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THE LIFE OF THE UNIVERSE

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BY

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THE
LIFE OF THE UNIVERSE

VI

FROM NEWTON TO LAPLACE
MECHANICS AND COSMOGONY OF THE SOLAR SYSTEM

KEPLER'S discovery of the laws of the planetary movements had rendered it possible to predict the positions of the planets for a certain time. The main link in the chain of evolution was yet missing, however, and it was reserved to Newton to add it. He proved that the three laws of Kepler * could be deduced from one single law, viz. from the now universally accepted law of

* The three laws of Kepler are: I. The planets move in ellipses about the Sun, which is situated at one of the foci of the ellipses [each ellipse has two foci, and the Sun is at the one common to all the ellipses]. II. For each planet the radii vectores [lines drawn from the Sun to the planet] sweep over equal areas in equal times [which implies that the Earth moves faster in winter, when nearer the Sun, than in summer]. III. The squares of the periods of two planets are to one another as the cubes of their mean distances from the Sun. I and II were published in 1609, III in 1619.—H. B.

gravitation: the force acting between two masses is proportional to their mass and inversely proportional to the square of their distance. The intensity of the force of gravitation on the surface of the Earth was at that time known from the measurements of Galilei and Huygens. Since now the same force, in this instance, the attraction of the Earth acts, according to Newton, upon the Moon and keeps it within its orbit, the intensity of gravitation should have admitted of a comparative determination from the known distance of the Moon and the curvature of its orbit. Newton made that calculation in the year 1666, but he did not arrive at any satisfactory result.

It is not at all improbable, as Faye remarks, that Newton was induced by this failure to doubt the universal character of gravitation. It is certain that he did not resume his calculation before the year 1682, when it led to the desired result, being based upon more recent estimates of the size of the Earth. We may presume that the time was ripe for this discovery, as the saying goes. For four countrymen of Newton had already come very near making it. In any case it was welcomed with enthusiasm by almost all the contemporaries of Newton. Yet it remained very difficult to conceive, how the bodies could act upon one another at a distance, and how the planets could move in empty space. Their movements were so extremely regular that one could not

possibly suppose them to pass through any gaseous matter, be it ever so attenuated. Moreover, observations conducted with the barometer proved that the density of the air decreased rapidly with the height above the surface of the Earth. The Cartesian vortex theory had hence to be abandoned. All the heavenly bodies, including the comets, which had given Descartes so much trouble because their orbits deviate so greatly from circles, moved in paths which rigorously obeyed Newton's law.

The striking regularity and uniformity which prevails in the planetary system, was a mystery to Newton. In addition to the six then known planets, their ten satellites all move in the same direction, all nearly in the same plane, the ecliptic, and all in almost circular orbits. As Newton did not believe in any vortex movement, which would carry the celestial bodies along with it, he could not understand this peculiar regularity, and all the less, because the comets whose orbits seemed likewise to be dependent upon the attraction of the Sun, frequently did not at all move in the same direction as the planets. Without any justification, Newton drew the conclusion that the regularity of the planetary movements could not have any mechanical cause. He argues somewhat as follows: On the contrary, the marvellous arrangement, by virtue of which the planets move in almost circular paths and

are kept far apart from one another, therefore, and the suns are so far distant from one another that their planets cannot interfere with one another, must have been caused by an intelligent and omnipotent Being. According to Newton the planets had received the impulse to their motion by the creation. This assertion, which really is the opposite of an explanation, was most determinedly contested by Leibniz; a positive solution of the problem was, however, not arrived at.

The first who seems to have aspired to such an explanation was Buffon, the ingenious author of the "Histoire Naturelle" (1745). Buffon knew the writings of Descartes and Swedenborg, and as he rightly considered the manner in which Swedenborg imagined the separation of the planets from the Sun was unsatisfactory from a physical standpoint, he looked for another explanation. From the outset he emphasised the extraordinary improbability, that the inclination of the ecliptic to the plane of the planetary orbits would, by itself and merely owing to chance, never exceed $7\frac{1}{2}°$ or $\frac{1}{24}$th of the largest possible inclination of 180°.

That point had already been accentuated by Bernoulli. The probability, that this inclination is mere chance, amounts for every single planet only to $\frac{1}{24}$th. For the five then known planets taken altogether the probability assumed the

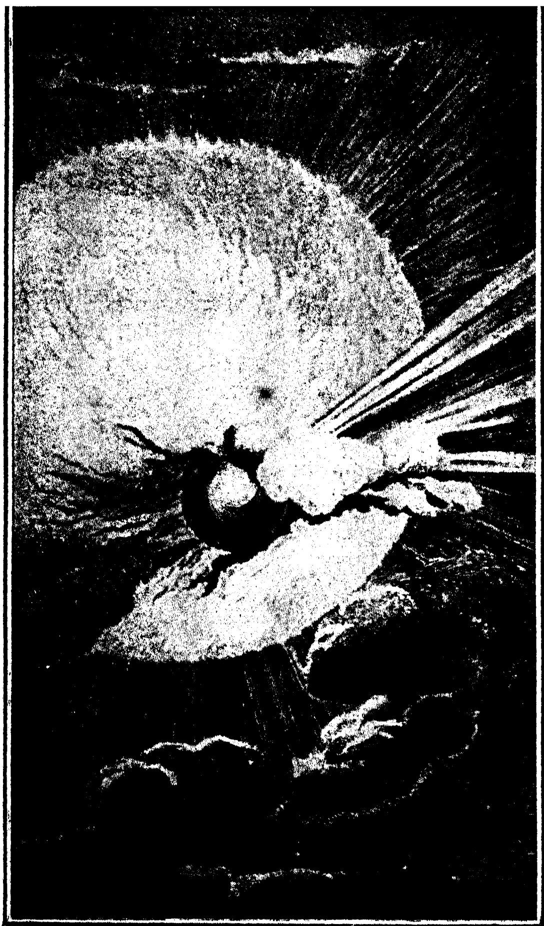


FIG. 21. Collision between the Sun and a Comet. Copper engraving in Buffon's "Histoire Naturelle."

value of 24^{-5}, or one eight-millionth. They had to consider in addition that the satellites, so far as then known, namely, the five moons about Saturn, four about Jupiter, the one of the Earth, and the ring of Saturn, were all moving in planes which deviated little from the ecliptic. A mechanical cause had to be found in explanation of these facts.

In order to explain the movements of the planets Buffon supposed that the planets had all arisen from collisions between the Sun and comets. About $\frac{1}{650}$th of the Sun's mass was assumed to have been knocked off and shifted, and out of that mass the planets and their moons were supposed to have been formed (Fig. 21). That such a tangential impact might occur seemed to be proved by the observation that the comet of the year 1680, whose orbit Newton had been calculating, had passed the Sun's luminous surface at a distance of only one-third of the solar radius; it seemed thus indeed possible that the next time, when the comet was expected to return, in the year 2255, it would fall into the Sun.

The objection may be raised that the fragments of the Sun would fall back upon it. Buffon's reply was that the comet would have displaced the Sun laterally, and that the original path of the torrents of matter which had been thrown out would to a certain extent have been altered by fragments ejected at a later stage. This suggestion was later approved of by Laplace, who

critically examined Buffon's explanation. The idea of Buffon is indeed ingenious. If we imagine a round disc of wood, into which a sharp tool is penetrating so that shavings are knocked off, as

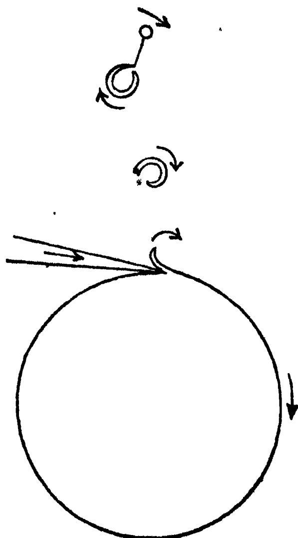


FIG. 22.

indicated in Fig. 22, the disc will assume a rotation in the direction of the arrow. The shavings which are split off will rotate in the same direction and they will further, owing to friction against the tool, be moving towards the right, that is to say

in the same sense and parallel to the direction of the movement of the equator of the disc. Smaller shavings, fragments of larger pieces, would commence to whirl about the larger pieces in the same sense, because they would be held back in the first instance by some finer fibres. In the same manner the fragments of the Sun, which had been produced when the comet penetrated obliquely to the surface of the Sun, would all rotate in the same direction and would, after the impact, travel in the same direction as the particles near the solar equator. Buffon regarded the Sun as a solid incandescent body, surrounded by an atmosphere and otherwise resembling the Earth. The little fibres, by the aid of which the small shavings were retained by the larger, would be replaced by the force of gravitation.

So far everything was right and good. Buffon went further. He argued in this way. Those fragments which possessed the smallest density would attain the greatest velocity and would therefore be hurled furthest away from the Sun, before their orbits would begin to curve. As he knew, that Saturn had a smaller density than Jupiter, and that the density of Jupiter in its turn was smaller than that of the Earth, he arrived at the conclusion that the planets would be the more dense the nearer they were to the Sun, a conclusion which had been drawn, as pointed out above, by Swedenborg and which reoccurs in Kant, but

which does not at all accord with our present knowledge. Further, the fragments which, at the moment of their separation from the Sun, possessed the largest equatorial velocity, would most easily have split off smaller fragments of their own, i.e. satellites. This assumption appeared justified in the light of the knowledge of those days, but is no longer so. People knew at that time only, that the equatorial velocity of Jupiter was greater than that of the Earth, and that of the latter greater than that of Mars. They knew, as mentioned, four moons of Jupiter and one moon of the Earth, but they did not know any moon of Mars. Saturn having five moons would hence possess the greatest equatorial velocity. Since then, however, we have arrived at the following sequence in equatorial velocities: Jupiter, Saturn, Earth, Mars, and at the following number of moons 8, 10, 1, 2. The above argument can, therefore, no longer be accepted.

The enormous evolution of heat caused by the collision would probably render the planets liquid, Buffon thought, but they would rapidly cool again owing to their small size, as the sun would cool and be extinguished some day. The different planets would remain incandescent for longer or shorter periods, according to their sizes. From experiments on the rapidity of cooling, which Buffon conducted with incandescent balls of iron of different diameters, he thought himself justified

in concluding that the Earth had required some 75,000 years to cool down to its actual temperature. To the Moon he assigned 16,000 years, to Jupiter 200,000 and to Saturn 131,000. The Sun would require ten times as long a time again as Jupiter.

In separating from the Sun the planets would have passed through the atmosphere of the Sun, and they would absorb from it air and water vapour, from which seas would later on be condensed. Long before that the interior of the Earth would have ceased to be incandescent, since no air could penetrate into it to feed the internal fire (this contradicts Descartes and Leibniz). Buffon believed that only two per cent of the terrestrial heat was being supplied by radiation from the Sun; the rest he considered the Earth's own heat. He further stipulated the same density for the Earth throughout its mass, because otherwise its axis of rotation could not have maintained a symmetrical position. But the shape of the Earth is exactly that which a liquid sphere of the rotational velocity of the Earth would assume. Nor is the Earth hollow; because gravitation would otherwise be greater on high mountains than it is.

The mean density of the fragments is almost the same as that of the Sun. For Jupiter, which makes up the chief mass of the planetary system, constituting about 75 % of it, has nearly the same

density as the Sun, and Saturn which ranks next to it in size has a slightly smaller density. The inner planets, however, possess a greater density than the Sun. In these factors Buffon finds a confirmation of his views. As regards the latter two points, it should be remarked, that the rotational axis of the Earth would even then pass through its centre and through the poles, if the density at a point of its interior should only vary with its distance from the centre. Hence there would be nothing against the assumption that the Earth is denser in the interior than in its exterior strata, and we believe now that the ratio of the two densities is about 2 : 1. Further, the cooling of the Earth need not proceed at so rapid a rate as in the case of a ball of iron, which is a very good conductor of heat. The Earth may still be incandescent in its interior, although no combustion process is being carried on there. And finally we believe at present, that the Sun and probably also the outer planets comprising Jupiter, as well as the interiors of the inner planets, are gaseous and not, as Buffon surmised, solid. Under these circumstances his deductions practically lose their force; but they are incomparably superior to the view to which Kant later gave expression.

Buffon was a real scientist, who reasoned as we do at present. He was made the object of Laplace's criticisms, which were not unjustified,

and on this account his name is rarely mentioned now, whilst Kant and Laplace are always brought to the front. Yet it appears to me that Buffon's exposition well deserves a place next to that of Laplace, especially since it is fifty years older than the latter and Laplace by far surpasses the philosopher of Königsberg.

Buffon passes a rather bitter and yet apposite censure on the prolix and obscure cosmogonics of his time in the following words:

"I might have written as thick a book as Burnet or Wiston, if I had wished to expand my opinions in their manner, and I might have given weight to my deductions by clothing them in mathematical garments, as the latter has done. But I believe that hypotheses, however probable they be, should not be treated by such apparatus which savours just a little of charlatanism."

Laplace has rightly raised an objection to Buffon's system which no doubt has brought Buffon's theses into discredit. Buffon himself says: If a projectile be discharged from some point on the Earth, it will, if it describe a closed path, return to its starting-point and therefore remain only for a short time separated from the Earth, at the most for one revolution. In the same way the little split-off fragments of the Sun would turn back to the Sun. That they do not do so, is due to several additional circumstances. On this point the great authority in the domain of celestial

mechanics states: "The impacts, which the different particles that have successively separated will impart to one another, and their mutual attraction may alter their sense of movement, and their perihelia, that is to say, the points of their orbits nearest to the Sun, may recede further from the Sun." So far Buffon is right, therefore. But Laplace continues: "Nevertheless their orbits must be strongly eccentric, or it appears at least extraordinarily improbable that they should all be almost circular." Buffon had well understood that the orbits of the planets were approximately circular, but he had been unable to give an explanation of this regularity. His system had to be considerably modified therefore to make it conform to reality. It is, on the other side, very difficult to understand Laplace's remark, that Buffon would not have been able to explain the extremely eccentric orbits of the comets. For Buffon did not believe at all (as Kant later did) that the comets belonged to the solar system. He agreed with Laplace in assuming that they were immigrants from outer space. Under these circumstances their orbits could not but be strongly eccentric, as Laplace demonstrated. Buffon has not discussed this question at all. That may be a defect or an omission, but it cannot be characterised as a mistake.

We pass now to the work of Kant, twelve years later than Buffon's and inspired by him, and we

shall see that it cannot bear a comparison with Buffon's work.

Kant was a young man of thirty-one years and had not yet entered upon his brilliant philosophical career, when he published, in 1755, his book "Naturgeschichte und Theorie des Himmels," in which he deals with the just mentioned problems under application of Newton's laws. His cosmic space was empty, and the planets could not be carried through it by any vortices in the sense of Descartes. But provided the planets had once been set in motion, no further impelling force was needed for them in empty space. Why could we not assume, then, that the vortex which had started these planets on their trajectories had once existed and disappeared afterwards? That was Kant's happy line of reasoning; it somewhat recalls that of Anaximandros (compare p. 68).

"I therefore presume," Kant says, "that in the beginning all the matter which is now in the Sun, the planets and in the comets, must have been spread through the space in which these bodies now circulate." The attraction of the particles was directed towards the centre of this mass of dust, there where the Sun stands now. The material particles at once began to fall towards the centre of the mass. Kant imagines these particles solid or liquid; for he remarks, that the specifically heaviest particles would have the greatest probability of falling down upon the

Sun. It would sometimes happen that particles knocked against one another and were laterally deflected. Thus movements in closed paths—Kant speaks of circular orbits—would arise about the centre. The bodies, which moved in these paths, would again and again collide with one another, until these repeated collisions would have produced such a grouping, that they all moved in circular paths and in the same direction about their common centre. Some of the bodies, which were falling towards the centre, would likewise assume the same movement and would cause the Sun to rotate about its axis in the same direction.

Since now the distribution of matter about the centre was originally uniform, why should the final movement be from right to left, and not just as well from left to right? Aristoteles thought that the latter sense of movement, which he presumed for the celestial bodies turning about the Earth, was superior, more worthy of the gods. Kant holds that one of the two directions would prevail. That would be correct only if the material particles had from the very first possessed a vortex movement in some definite direction about a given point, as Descartes had supposed. But Kant does not make this hypothesis, and hence his exposition does not permit of the formation of a planetary system endowed with a definite predominating sense of rotation. It is strange that the great philosopher

Herbert Spencer should, a hundred years later, have fallen into the same mistake.

Kant further believed that in the matter once in vortex motion the heaviest particles would have the best chance of penetrating right through to the centre, before they had time to assume the final circular movement. For this reason the planets nearest to the Sun would possess the greatest density, as Swedenborg and Buffon had already asserted. But this is not so. Kant also maintains, that the central body would be specifically lighter than those nearest to it. But the Moon is less dense than the Earth; Kant, we must add, was of the opposite opinion.

In the rings of meteoric dust which moved about the Sun there should be some portions of greater densities, and the other matter should gradually become concentrated about those parts. In that way planets and comets were said to have been formed. If the distribution of the particles in the rings were perfectly symmetrical, the planets would attain perfectly circular orbits, all situated in the same plane. Kant suggests that the deviations of the planetary orbits form circles and their inclinations to the ecliptic could be explained by a pre-existing want of symmetry. It is inexplicable, however, how such a want of symmetry could be pre-existing, since he had presumed a uniform distribution of matter about the Sun as centre during the course of its formation.

In another place he suggests that the smaller the intensity of gravitation, that is to say, the greater the distance of the planet from the Sun, the greater would also be the eccentricity of the planetary orbit. This is correct, as Kant states, for Saturn, Jupiter, Earth and Venus; but he does not mention Mercury and Mars, which show the greatest eccentricity after the minor planets, and which therefore would not fit into his system at all. Kant regards with Descartes the comets as outside and beyond Saturn; that would explain their great eccentricity.

The incorrectness of this view had already been proved by Newton and Halley. According to Kant the comets would also be specifically lighter than Saturn, which is probably wrong in so far as the comet's nucleus is concerned.

We see, therefore, that Kant's cosmogony is based upon a number of hypothetical statements which are not in accord with the actual relations. It would be of little interest further to illustrate this fact. It is more important to mention that, as Faye demonstrated, a planet which had been formed in Kant's manner by the contraction of a ring would have received a rotational movement opposite to that of the Sun and of all the planets which were known in Kant's days. If we imagine a ring, such as is represented in Fig. 23, the particles of dust further removed would according to the laws of planetary movements travel with

smaller velocity than those nearer to the Sun. If then such masses of dust aggregate to a ball, that ball would revolve from right to left more rapidly on its interior side turned towards the Sun than on its exterior side. In other words the direction of the rotation would be from left to right, that is to say, opposite to that of the Sun.

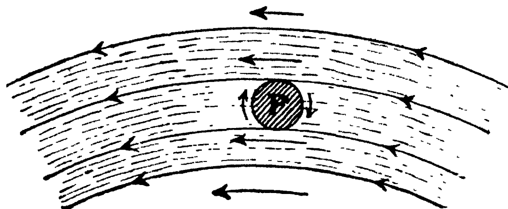


FIG. 23. Diagrammatic representation of a planet P which is in the course of formation from a circular stream of meteors moving about a centre situated below P.

The four central arrows indicate the velocities of the different portions of the swarm of meteors; this velocity decreases from below upwards. Since the rotational velocity is greater below P than above P, the latter will prevail in a collision between meteorites from the different belts, and P will therefore revolve in the opposite sense to the meteorites, that is, from left to right instead of from right to left.

It is peculiar that Kant offers a mechanical explanation for the formation of the rings of Saturn which fairly agrees with that given by Laplace for the formation of our planetary system. He starts from the assumption, that the whole mass of Saturn must originally have had a very large extension and must have

rotated about its axis. When it began to contract, some particles soon attained too high velocities to fall back upon the surface. They remained outside and formed ring-shaped collections of satellites. He also believes that the moons of Saturn may have arisen in a similar way. That he does not presume a similar original rotation for the evolution of the solar system, demonstrates how little he had really worked out this line of reasoning. In the Zodiacal Light he sees a faint ring formation about the Sun. There is another weak point in his reasoning. Kant imagines that those particles furthest inside the ring would originally have been on the equator of the planet and would from that position have risen to their actual height without change of velocity, an idea which is in direct contradiction to the laws of gravitation. He then calculates the velocity of Saturn at the equator from the period of the ring and he arrives at a period of revolution of 6 hours 23 minutes and 53 seconds. He is very proud of this result, "perhaps," he thinks, "the only prediction of its kind in the whole domain of natural philosophy." The period of Saturn, however, is 10 hours and 30 minutes. In this connection Kant also attempts to give an explanation of the deluge, a subject which greatly occupied the attention of the learned men of his day. The water under the firmament, which is mentioned in the first book of Moses, Kant thinks, was probably a ring-

shaped mass of water-haze about the Earth, somewhat similar to the ring of Saturn. This terrestrial ring was supposed to have served for the illumination of the Earth and, when man showed himself unworthy of this privilege, to have been used for punishing him. The ring suddenly fell upon the Earth and flooded it. Similar attempts of scientific interpretations of Biblical and classical tales reoccur over and over again in the scientific publications of that age.

Kant took up an idea advanced by Wright in the year 1750, according to which the mean plane of the Milky Way would correspond to the ecliptic of our planetary system. Just as the planets which move about the Sun do not travel far away from the plane of the ecliptic, so the stars would move in paths which little deviate from the mean plane of the Milky Way. These stars, to which our Sun also belongs, would themselves move about a central body whose position was unknown, but might possibly be ascertained by means of observations. According to Nyrén, Wright has put all the important features of this thesis quite as clearly as Kant.

Finally Kant has dwelt upon the extinction of the Sun. According to the then common view the Sun was a burning celestial body, and the end was to come from want of air and from accumulation of the ashes.

While burning the Sun had lost its most volatile

and finest particles, which formed the cloud of dust which he assumed to be the seat of the Zodiacal Light. Kant hints very obscurely that "the law concerning the extinction of the Sun includes a germ for the reunion of the dispersed particles, even if the latter should have intermingled with the Chaos." According to this passage and to some others, to which we shall revert again, Kant seems to assume that matter passed through a cycle of evolution, being now condensed to suns and then again scattered into chaotic confusion (compare the views of Demokritos, page 72).

Kant's cosmogony belongs to that class of theories according to which the planetary system originated from cosmic dust or a collection of small meteorites. This idea has been taken up later by Nordenskiöld and Lockyer and has been mathematically worked out by George Darwin. The latter has shown that a collection of such small bodies would in many respects behave like a mass of gas.

Laplace on the contrary, when attempting to give a mechanical explanation of the evolution of the solar system at the end of his "Système du Monde," starts from the assumption of a glowing mass of gas which from the very first was in vortex motion from right to left (as viewed from the north) about an axis passing through its centre of gravity. The difference between the two theories is essential, but has often been over-

looked. That may possibly be due to a statement made by Zöllner with regard to the nebular hypothesis, in which he intends to demonstrate that "this hypothesis was not founded by Laplace, but by Kant, Germany's philosopher."

The exposition of Laplace may be summed up as follows: "In its primitive assumed condition the Sun resembled those nebulæ which (compare Herschel's discoveries, page 149) are shown by the telescope to be composed of a more or less brilliant nucleus, surrounded by a nebulosity which is condensing upon the nucleus transforming it into a star. The solar mass cannot have extended out indefinitely. Its limits were the points, where the centrifugal force due to its motion of rotation was balanced by the gravitational attraction." The nebula contracted on cooling. From Kepler's second law each particle would in the unit of time (a second) describe an arc whose length would be inversely proportional to the distance from the Sun. The centrifugal force would consequently increase inversely as *the third* power of the distance from the centre, while the inwardly directed gravitation would increase inversely as the second power of the same term. When therefore the contraction of the glowing mass of gases continues, a gaseous disc is split off, as soon as the two forces become equal, and travels about the Sun like a planet (Fig. 24). Laplace hence assumes that the solar nebula would divide into rings of

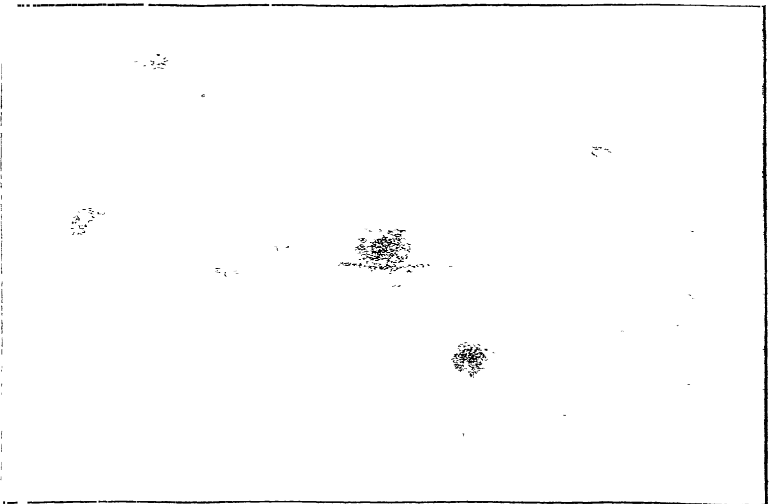


FIG. 24. Diagram of ring formation from a nebula, according to Laplace. While the nebula is contracting, rings are formed about its centre, the Sun. Some of the rings have burst; in some condensations of nebulous matter are seen which are transformed into planets. From "Weltall und Menschheit."

glowing gases, each of which would rotate as a whole and cool down to a solid or liquid ring.

This, however, is physically impossible. During the cooling small dust particles would segregate and float in the gaseous medium. These particles would gradually grow to larger aggregates, on which gases would be condensed. Rings of dust would result, such as Kant imagined about Saturn, and these would after aggregation to planets turn in a direction opposite to the observed. Stockwell and Newcomb have, moreover, shown that such a coalescence to a single big mass could not take place. There would result, in its place, a collection of small meteorites such as circulate in the Saturn rings. According to Kirkwood the transformation of the Neptune belt into a planet would have required not less than 120 million years.

Further, all the planetary orbits would be circular and lie in the same plane. Laplace certainly says: "It may be conceived that the endless variety in the temperature and density of the various parts of this great mass produced eccentricity of their orbits and deviation of their motions from the plane of its equator." But he does not himself appear strongly convinced of this opinion, since he remarks later on, that comets (which in his opinion are strangers to the planetary system) came near the Sun and, colliding with planets in the course of formation, caused them to

deviate. Other comets would have entered the system when the condensation of the gaseous matter was nearly completed; they were so much retarded in their movement that they were incorporated into the solar system, keeping, however, an oval, long-drawn-out trajectory.

The most serious objection to the thesis of Laplace is probably the retrograde movement of the moons of Uranus and Neptune. The most remote moons of Saturn and Jupiter are likewise retrograde, while the other, inner satellites of these two planets turn in the normal sense.

We see that Laplace, while avoiding certain difficulties of Buffon's thesis (the small deviation of the planetary orbits from circles), is confronted by others not less serious. But Laplace gives us an excellent idea of the origin of the rings of Saturn.

The great contemporary of Laplace, Frederick William Herschel (born at Hanover in 1737, died at Slough near Windsor in 1822), studied the nebulæ with his telescope. They seemed to show stages of evolution (1811). Some nebulæ shed a diffused, greenish phosphorescent light; that appeared to be the primitive stage. Spectrum analysis has confirmed this view; the luminous masses consist of gases, chiefly hydrogen and helium, and an otherwise unknown substance, nebulium. In other nebulæ Herschel observed a faint central condensation nucleus. In others again he distinctly dis-

cerned stars; and there were others finally, in which the nebulous matter had almost vanished, being replaced by clusters of stars.

These simple, though most extensive observations have stood the test of subsequent examination much better than the highly admired thesis of Laplace. It should in justice be acknowledged, however, that Laplace apparently did not wish to give prominence to his thesis. For he published it as a note at the end of his classical work: "Exposition du Système du Monde."

This is the great work in which he inquires into the stability of our solar system. His conclusion is: "Whatever be the masses of the planets, it is only owing to the circumstance that they all move in the same direction and in almost circular orbits, at small inclinations to one another, that the secular variations in their orbits are periodical and within narrow limits, and that the system therefore oscillates about a mean condition, from which it never deviates by more than an insignificant amount." Laplace also demonstrated that the length of our day has not changed by as much as $\frac{1}{100}$th of a second since the year 729 B.C.

This conclusion, as to which he had the support of Lagrange, more firmly established the Newtonian doctrine of the wonderful stability of our solar system. It seemed to guarantee to the planetary system an eternal existence—strange enough, when

we remember, that the system was supposed to have had a beginning.

In this respect Kant's view is, no doubt, more consistent, or at least more in accordance with modern ideas.

VII

MORE RECENT ASTRONOMICAL DISCOVERIES THE STELLAR UNIVERSE

WHILST Laplace confined the deductions, which we have just been discussing, to our planetary system, and while Swedenborg, Wright and Kant only expressed general opinions concerning the other cosmic bodies, of which opinions the most remarkable is perhaps that of Wright, that the stars of the Milky Way, as well as our own Sun, are always moving, Herschel made the whole immense stellar Universe his field of research. Halley (1656-1742) had already succeeded in observing that some stars had changed their position in the course of centuries and even in the time interval between Tycho Brahe and the end of the seventeenth century. Soon afterwards Bradley (1692-1762) mapped out his stellar catalogue with a hitherto unattained degree of exactitude. Herschel, who had this catalogue at his disposal in his inquiry into the change in position of the stars, observed that those changes were indeed quite considerable. He also noticed that

the stars seemed to be approaching one another in a certain portion of the sky, whilst they seemed to recede from one another in the opposite portion, and he explained this phenomenon by the change in the visual angle under which the objects appear. When we approach an object, the angle becomes larger, and when we recede from it, it becomes smaller. The objects are in this case the lines joining the stars. Starting from this base Herschel was able to determine the point, towards which the Sun and the constituents of its system are travelling.

This motion of the stars, first observed by Halley and then studied by Herschel, is known as the proper movement of the stars. It is generally determined by measuring the displacement of the stars on their background, the sky which is strewn with a multitude of stars at extraordinarily great distances. In most of those latter stars no movement whatever can be traced.

Great discoveries are generally received with doubt. No less a man than Bessel maintained that Herschel's discovery was doubtful. Argelander, on the other side, who deserves the greatest credit for his extraordinarily careful measurements of the stars and their positions and light intensities, supported Herschel, and his opinion has been confirmed by the later astronomers, among whom Kapteyn should particularly be singled out. The following pages are partly taken from Kapteyn.

Fig. 25 illustrates the movements of stars in a portion of the sky which is situated between the triangle, Andromeda, the Ram, and the Fishes. The small black dots indicate the present position of the stars; the straight lines starting from the dots indicate the paths along which these stars are expected to travel during the next three thousand five hundred years. We see at a glance that the constellations will look very different at the expiration of that period. The stars do not by any means move in parallel orbits, nor with equal velocities. Yet we distinctly recognise a predominating direction of movement, obliquely downward to the left. If we trace all the movements from one origin, as is done in Fig. 26, we clearly recognise this predominating direction. It is marked in the diagram by an arrow with a double shaft (Fig. 26).

When we plot such resultants of the directions of movement on the celestial globe we come to Fig. 27. The different arrows all radiate from one point of the heavens, which is designated the apex, and which is obviously that point towards which the Sun seems to be moving; for the stars appear to be receding from it in all directions. Of course, this holds only for a mean or average movement of the stars. Every single star will in its proper movement differ more or less from its mean. Hence it is evident that the stars must relatively become displaced, and that it is not the Sun alone

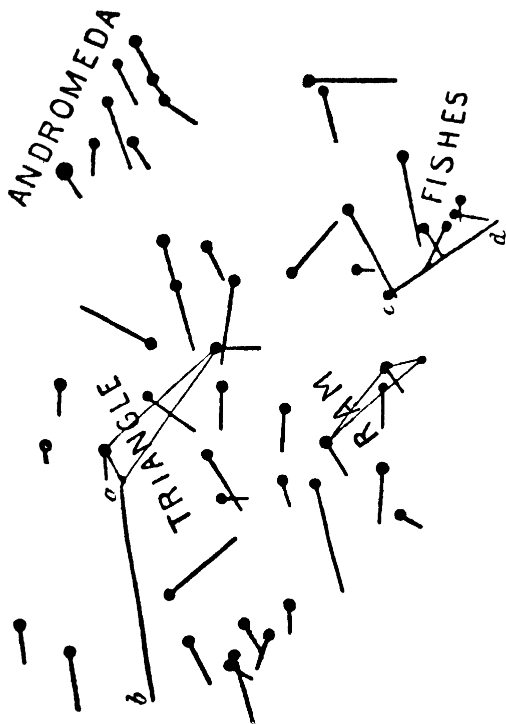


Fig. 25.

among all the crowds of star systems which is progressing. This last figure (27), which is due to Kapteyn, affords an extraordinarily instructive picture. For it proves incontestably that Herschel was right in his assumption. The Sun moves towards the point A on the sky situated in the constellation of Hercules, near its border on the side of the constellation of the Lyre. The Sun recedes from the constellation of the Great Dog, which is on the opposite side of the sky.

Schönfeld and Kapteyn have examined the assertion of Wright, that the stars of the Milky Way move in the same direction like the planets of the solar system. No certain indication of such a regularity has been demonstrated. But Kapteyn deduced another regularity. The proper movement of the stars seemed to him to suggest the existence of two distinct star streams. One of these is directed towards the star Xi in the constellation of Orion, the other in exactly the opposite direction. The further inquiry into these regularities should furnish us with most interesting clues.

These phenomena acquired a still higher interest, when we succeeded in determining the distances of some fixed stars from the Sun. We rely on their apparent movements in the sky in the course of a year. According to the views of Aristarchos and of Copernicus the Earth is moving in space. It must, therefore, at one time of the year be nearer

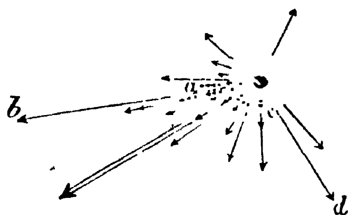


FIG. 26.

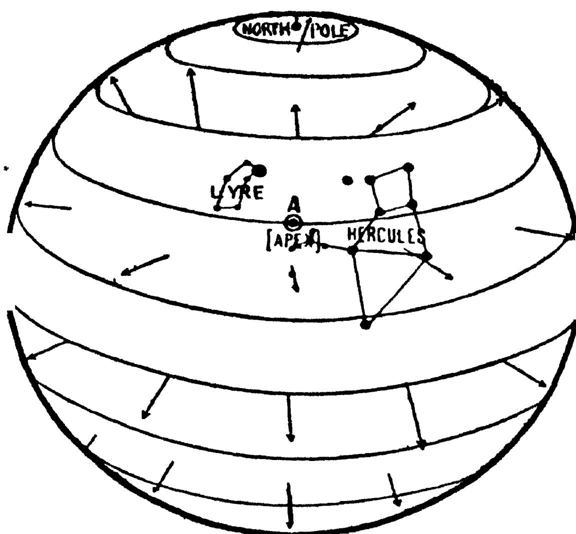


FIG. 27.

a certain star than in any other time of the year. We might then expect to notice certain changes of periodical nature and hope to find that the same constellation would alternately increase and decrease in size or brightness in the course of the year.

All attempts to verify such variations failed, however, and people were satisfied, as Aristarchos had been, that with the enormous distances of the stars the change in the visual angle, if any, could not be observable. Copernicus shared this opinion. Tycho Brahe considered variations so altogether out of question, that he saw in that fact one more reason to assume the Earth as fixed in space and as the centre of the Universe. The astronomers, however, never tired in their efforts to investigate this point further, and Arago and Bessel succeeded at last in 1809 and 1838 in establishing a very small annual to-and-fro movement (the stellar parallax) in the star 61 of the Swan. From this movement the distance of the star was derived. It proved so great that light would need ten years to travel from this star to the Sun; the distance amounts to 10 light years, as we say. One light year indicates $9{\cdot}5 \cdot 10^{12}$ or about ten billion kilometres, or 63,000 times the distance of the Earth from the Sun.

The distances of other stars have been determined with our ever-improving instruments. The star Alpha Centauri seems to be nearest to our Sun,

though the distance between the two yet amounts to 4·3 light years. Eight stars, among them Sirius, are distant 10 light years and less. The mean distance between stars in our portion of the Universe is a little more than 10 light years. We know of 28 star neighbours at distances of less than 20 light years, and of 57 stars within less than 30 light years. Aristarchos and Copernicus were right, and with this demonstration the last doubt as to the movement of the Earth in its own orbit was disposed of. When we know the proper movement, that is to say, the angular velocity and also the distance of a star, we can calculate their real velocity. This method, however, only yields us that component of the velocity which is at right angles to the line of sight. The following examples may be quoted: The velocity of Vega is 10 km., of Alpha Centauri 23, of Capella 35, of 61 in the Swan 60, and of Arcturus about 400 km. per second.

If we further know the velocity of the star in the line of sight, we can calculate its total movement. Spectrum analysis, which has altogether revolutionised stellar astronomy since its introduction in 1859, and the Doppler principle allow us to make even this determination. These velocities amount for the five just mentioned stars to −19, −20, +20, −62, −5 km. per second. A plus indicates that the star is moving away from the Sun, a minus that it is approaching the Sun.

The figures show that the stars have relatively great velocities. For the velocity of the Earth in its orbit is about 30 km. per second.

The point on the sky towards which the Sun is moving can still more easily be derived from the motion of the stars in the direction of the line of sight than from their proper movements. Campbell found in such a calculation that—assuming that the reference stars are on average stationary, that is to say, that as many of them move away from the Sun as towards it, and with the same velocity—the Sun would travel with a velocity of 20 km. per second towards a point which coincides very nearly with the spot calculated from the proper motions of the stars. We need no longer doubt, therefore, that the observed phenomena have been correctly interpreted. It would be of the greatest interest to ascertain whether the Sun is always approaching the same point in the sky and thus moving in a rectilinear path, or whether this path is slightly curved. From the magnitude of the curvature we should be able to determine which forces are influencing the movement of the Sun through space. The observations have, however, been carried on for far too short a period as yet to enable us to answer this question.

It is certain, however, that the stars are not all moving about one great common central body, like the planets about the Sun, in the sense that

Wright and Kant believed. Their motions in fact appear quite irregular. It is not improbable, therefore, that in its adventurous wanderings, the Sun might at some time or other encounter another star or a nebula. The Sun may have to travel for a hundred thousand billion years before it collides with another star of similar size and light intensity. But this period of undisturbed wandering may be greatly shortened, because there is probably a far greater number of extinct suns, than of luminous suns floating about in space. It would not be strange if the Sun were to drift into some nebula. They abound in the Universe, and many of them are seen to occupy immense areas, while even the most brilliant stars are mere points in our most powerful telescopes. It is often suggested that the Sun would be impeded in its course through such a nebula, and that the friction would raise its temperature to incandescence. It would then become a so-called new star, like the one which flashed up in Perseus in the year 1901. The following consideration will show that this latter conclusion cannot be correct. According to Laplace the mass of the solar system once formed a nebula which had spread out to a disc and which extended to the limits of the orbit of Neptune. If we assume the thickness of this disc to be on average not greater than ten times the actual solar diameter, the density of this nebula would yet approximately be 420 million

times smaller than that of the Sun. If the Sun were to enter such a nebula with a relative velocity of 28·3 km.* per second, it would in the course of a year, traverse a mass of gases which could not be greater than two millionths of its own weight. The velocity would correspondingly be diminished. That would cause an increase of the mean temperature of the Sun by about 0·2°, presuming the specific heat of the Sun to be equal to that of water. But that coefficient is probably greater; for in general the specific heat of a body increases considerably with rising temperature. Even if this rise in temperature were chiefly confined to the external layers of the Sun and of the gases of the nebula with which it collided, the rise in temperature could yet be only very slow, and no sudden flashing-up could result, as in the case of the formation of new stars. Moreover an increase in the radiation of the solar heat by ten per cent would suffice to prevent any further increase of temperature. Such a small change in the brightness of the star would scarcely attract our attention. The nebula in its exterior portions would moreover be very much more attenuated than the above mentioned average figure.

* This number is the probable resultant of the relative velocities of the Sun and a nebula, each of which is moving with a velocity of 20 km. with regard to its surroundings. According to Campbell's determinations the velocities of nebulæ are of the same order of magnitude as that of the Sun.

A flashing-up might ensue only in case the Sun should collide with another star or should drift into the central concentrated portions of a nebula. The luminosity might then become several hundred or thousand times as large as before and afterwards, and the phenomenon would be suggestive of the formation of a new star.

Nebulæ may, on the other hand, be able to accelerate the occurrence of collisions between suns. A great deal of matter is collected in the nebulæ, having drifted into them from all sides and all portions of the heavens: Meteorites, comets, and above all cosmic dust. These wanderers through space possess so small a mass that they would be stopped by a nebula; nebulous matter would condense upon them, and they would gradually coalesce into larger bodies. The consequence would be the formation of small stars. If now the Sun should in its travels approach such bodies and collide with them, vast torrents of gaseous matter would project from the Sun and would reduce the velocity of the Sun. Its further motion through the nebula would thus be impeded. In this sense suns may finally be caught, so to say, after having for long periods wandered through nebular masses which occupy immense spaces. There is much more probability of a collision between a sun which has once drifted into a nebula and another sun, which has already been

caught in it, than of a collision between two suns, both travelling through the almost void space.

For all these reasons we have to diminish considerably the period of free travel which we allowed to the Sun for its motion through celestial space. It may not be too much to go down to one-hundredth of the above stated figure, that is to say, to about a thousand billion years. It need not be pointed out that such estimates are quite uncertain, and that we merely intend to give an approximate idea of the length of the life periods of celestial bodies.

The probable consequences of a collision between two cosmic bodies of the size of our Sun have been described at some length in my book, "Worlds in the Making." Two enormous streams of gaseous matter would issue forth from the two suns in collision and, rushing out into infinite space, they would assume the appearance of a double spiral which characterises such nebulæ. The torrents of matter would consist essentially of the gases which are most difficult to condense, especially helium and hydrogen, further of small particles of substances which are more easily condensed. All these would be endowed, by the eruption, with so great a velocity that they might escape from the range of attraction of the central body. Having then lost their velocity, they would for long periods remain in an almost unchanged position without being deprived of

their spiral shape. Masses which were thrown out with less violence would return to the heart of the eruption and collide with others which were thrown up at a later period. The whole matter would finally form a gaseous nebula of vast extent, interspersed with solid and liquid particles, about the central body which (as Buffon had already suggested) the collision would cause to revolve at a high rate. Furthest inside we should find the central body in a state of violent incandescence; it would have increased its volume very considerably after the collision and would on the outside gradually pass into the gaseous matter which whirls around it.

Somewhat in this way Laplace imagined the nebula from which the solar system has arisen. If we modify the ideas of Laplace and adapt them to subsequent observations, we obtain a picture of how the evolution of a solar system may commence anew in a nebula. In this picture we find the views of Buffon and of Laplace amalgamated to a certain extent.

The bright star Arcturus which rushes on with a velocity of about 400 km. per second has the greatest known stellar velocity. Its distance from the Sun amounts to about 200 light years, and the light which it emits strongly resembles our Sun's light. It must therefore be of immense size. Indeed, it has been calculated that it may be 50,000 times as large as the Sun. We may picture to

ourselves the results of a collision between two such giant suns travelling with enormous velocity. The ejected masses of gas would spread out through an immense vortex, unlimited probably in all directions in the plane of revolution. We might imagine that the Milky Way owed its origin to a collision of this kind, if it were not difficult to account for the fact that we do not know any central body in it (compare the view of Ritter below). In such a gigantic nebula a large number of small stars would collect in the course of millions of years, and they would probably collide and produce new vortices. Almost all the new stars occur in the neighbourhood of the Milky Way in which the stars themselves are incomparably much denser and more frequent than in other parts of the heavens. Of new stars we see after their extinction merely gaseous nebulæ, and these gaseous nebulæ are found abounding to a remarkable degree near the Milky Way. When the nebular masses have had time to condense upon the dust and matter which have drifted into them, star clusters will arise which again are most frequent in this region of the sky. To judge by their spectra, the spiral nebulæ are star clusters which are so far distant from us that we cannot distinguish separate stars in them any longer. They occur particularly in those portions of the heavens where stars are relatively rare, at the poles of the Milky Way and thus at the greatest distance from

it. There, however, they abound. Wolf counted, for instance, on a single plate, on which he had photographed a portion of the constellation: the Hair of Berenike, no fewer than 1528 nebulæ, most of which probably belonged to the spiral class.

It is to spectrum analysis chiefly that we owe elucidation concerning the composition of the stars. Herschel classified the nebulæ according to the apparent state of their development, and in the same way stars have been classified. We begin with the hottest, those which give luminous spectral lines and which therefore are most closely related to the gaseous nebulæ from which they have probably arisen, and conclude with the darkest, probably about to become extinguished. After these luminous stars we have the dark cosmic bodies, first those devoid of any solid outer shell (Jupiter is a probable example), then those provided with a hard crust like the Earth (compare "Worlds in the Making," page 186).

Among the elements which are most prominent in the stars we find helium in the hottest stars; hydrogen in those white stars which follow next on the scale of temperature; calcium, magnesium, and iron, as well as other metals, in the yellow stars of medium temperature to which our Sun belongs; and finally carbon compounds, including cyanogen, in the least hot stars of reddish colour. It is not quite correct to assert that we have not

found in the stars any other elements than those known on our Earth. Pickering, for instance, observed in several stars spectrum lines which he could not identify with any terrestrial element. These lines have, on account of certain regularities in their wave-lengths, been ascribed with a considerable degree of probability to hydrogen, although we have not succeeded in causing hydrogen to emit this kind of radiation. A certain number of so far unidentified lines has also been found in the Sun. Of the spectrum lines which have been known for relatively short periods only, those of helium are the most important. The so-called coronal line which is characteristic of the inner corona of the Sun is one of the many unknown lines. Yet on the whole the spectrum lines of the stars and the lines of the terrestrial elements agree well. Maxwell said in the year 1873: We discover stars in space, by the aid of their light and exclusively by this aid, which are so far apart that nothing material can ever have travelled from the one to the other, and yet that same light tells us, that every one of those stars has been built up out of the same atoms that we find on our Earth. It is interesting to record that the same great scientist predicted in the same year the force by means of which matter might be transported from star to star, the radiation pressure. Three years later Bartoli demonstrated that it was not only

heat and light rays, but all kinds of radiation, which exercised this pressure in their radiations. Yet the cosmical importance of this new universal force was not heeded until I showed in 1900, that it admitted of explaining in simple ways many thus far inexplicable phenomena.

By the action of the radiation pressure small globules (spherical drops) of matter condensed in the solar atmosphere are pushed away from the Sun and wander through space with velocities which may attain a few per cent of the velocity of light. In the neighbourhood of stars whose radiation exceeds that of the Sun this velocity of the smaller globules may be very much increased, though it can never quite equal that of light. Indeed the high velocity appears to be the common rule; for most of the stars shed a white light in contrast to the yellow light of our Sun, and they radiate therefore at a higher intensity. Owing to this ejection of small particles which has been going on for uncountable ages, the suns are constantly exchanging matter. As a consequence any differences in the constitutions which might have originally existed would long since have been compensated. In this process, as in general in Nature, the colder bodies, in our case the colder stars, will gain at the expense of the warmer, and the larger will increase at the expense of the smaller.

It is not improbable, as I indicated in "Worlds

in the Making" (page 108), that the strange messengers from other worlds, the so-called meteorites, are composed of such spherules which had been driven into space. The meteorites are distinguished, by an entirely peculiar structure and composition, from all the rocks and minerals known on our Earth, from the so-called plutonic, which have been formed by the congelation of the liquid interior of the Earth, as well as from the neptunic, which have been formed upon the bottom of the sea. Frequently these meteorites contain enclosures of vitreous nature which suggest their having been cooled at a very rapid rate. In other cases they contain large crystals which indicate that they must have been exposed to the same temperature for long periods. Adjoining parts of the same meteorite may show striking differences in composition and in structure. That suggests that their materials must be of very different origin. They do not contain any water, nor any hydrates (compounds with water), and this appears quite natural; for their particles have been produced in the neighbourhood of the Sun, where hydrogen and oxygen have not yet combined into water. But they contain hydrocarbons, which are frequent in the spectra of the faintly luminous stars and of sun-spots, and further chlorides, sulphides and phosphides which are unstable on the Earth and which can only have been produced in an atmosphere which was devoid of

water and of oxygen. On the other hand the minerals which are common in our plutonic rocks are missing: quartz, orthoclase, acid plagioclases, mica, amphibol, leucit, and nephelin, minerals which have been produced by the so-called differentiation of the magma issuing from the interior of the Earth.

To bring about that differentiation a long-continued diffusion in large molten masses would be required, which cannot take place in small drops. All these peculiarities, as well as the very frequent fine-grain structure, which is designated chondritic structure, are easily compatible with the origin of these meteorites from small spherules. That large crystals are occasionally met with might be due either to the presence of some solvent (carbon monoxide for iron or nickel), or to the fact that a portion of the respective meteorites was for a long time exposed to intense heat, as would be the case of comets when they are near the Sun. Schiaparelli's classical investigations in this domain have proved that comets, especially when near the Sun, are resolved into swarms of meteorites.

These little drops which are ejected and propelled by the Sun will collect chiefly in the widely spread gaseous masses of the extreme portions of the nebulæ which owe their luminescence to the electrically charged dust. This light is characteristic of the peculiar gas spectrum of nebulæ.

In the intense cold of the nebulæ the drops will condense part of these gases, in particular the hydrocarbons and carbon monoxide, upon their surface. When such masses collide with one another they will be cemented by these materials. In this way small drops or spherules will gradually grow into meteorites which will continue their migration through space.

In addition to these particles, which are ejected by the radiation pressure, the suns exchange by their collisions part of their gaseous matter which will spread through space. Matter may also travel from sun to sun, because gaseous molecules of the outer portions of nebulæ may, by virtue of the radiation absorbed from far distant suns, attain so great a velocity that they separate from the nebula and rush out into space (compare "Worlds in the Making," page 195). Maxwell's opinion, that nothing material can have wandered from one star over to another, can therefore no longer be accepted.

The last twenty years have enlarged our knowledge of the nature of thermal radiation to an extraordinary extent. Among the laws established those of Stefan and of Wien are the most important. Stefan's law says that a body which does neither reflect any radiation, nor transmit it, will emit an amount of heat which is proportional to the fourth power of its absolute temperature (reckoned from $-273°$ C. as absolute zero). The

law of Wien teaches us, how the total radiation of a body is composed of many different kinds of radiations corresponding to the colours of the spectrum. The temperatures of the planets and moons provided with a solid crust can be deduced from the first law. This has first been done by Christiansen. The quantity of heat which the respective body receives from the Sun is known. As the body has a solid crust, it radiates almost as much heat into space as it receives from the Sun, and its temperature will therefore be approximately constant. The temperature can hence be calculated from the connection between radiation and temperature, such as results from the laws of radiation (compare "Worlds in the Making," page 46). In the case of planets and moons, which are not surrounded by an atmosphere, such as Mercury and our Moon, this calculation leads to correct values.

The presence of an atmosphere will change the relation to a certain extent, as Fourier pointed out already at the beginning of the nineteenth century. The reason is that the atmosphere transmits the incident solar rays to different degrees and generally to higher degrees than the heat rays emitted by the dark surfaces of the bodies. Water vapour and carbonic acid play an important part in these considerations, as I have discussed on other occasions. Most geologists agree, that the successive geological periods, of which fossil

organisms give evidence, were chiefly caused by fluctuations in the percentage of carbonic acid in the atmosphere, and this percentage again depends on the intensity of the volcanic activity of the period (compare "Worlds in the Making," page 52).

The knowledge of our planetary system has further been enriched in an important measure by our learning to determine the absolute mass of the Earth, from which its specific density could easily be calculated. Such measurements were first conducted by Cavendish in 1798. He compared the attraction which a large ball, 30 centimetres in diameter, exerted upon a small spherical pendulum, with the attraction which the Earth exerted upon the same ball. He deduced a specific gravity of the Earth of 5·45. Cavendish's experiments have since been repeated and modified by many scientists, and the final result is the figure 5·52 for the mean density of the Earth. Since now the outer strata of the Earth crust average a density of about 2·6 (that of the ordinary rocks), we have to assume that the interior of the Earth must be much heavier. Nevertheless we believe that the interior of the Earth, starting from a depth of about 50 km., must be liquid, since the temperature rises in bore holes by about 30 deg. cent. for every kilometre. The observations of the propagation of earthquake waves, as well as pendulum observations, confirm us in this assump-

tion (compare "Worlds in the Making," page 36). At still greater depths, of about 300 km., the whole nucleus of the earth would probably be gaseous. But the pressure at that depth must be so extraordinarily high, that it matters little for the density, whether the substances there are in the solid, liquid, or gaseous state. It is the temperature which is the really decisive factor. If therefore the planets nearest to the Sun have a much higher mean density than those further remote than the Sun itself, the reason would probably be that the former have a much lower mean temperature, and that the latter (by contrast to the others) probably are not enclosed in a solid crust. What we call surface in these celestial bodies, is merely that portion which we perceive through our telescopes and which consists of light clouds floating in the most extreme layers of the gaseous mass. The great mean density of the Earth seems to imply that the core must contain heavy metals. We have reason to assume in particular that iron is a very important constituent of the interior of the Earth, as well as of the metallic meteorites and of the Sun.

In the year 1675 the Dane O. Römer, assistant to the famous astronomer Cassini in Paris, made a discovery of the greatest astronomical importance. He found that it was possible to measure the velocity of light. He was observing the moons of Jupiter which Galilei had discovered. These

moons are obscured when they enter into the shadow of the planet, and these eclipses can be observed with the greatest accuracy. Since now the periods of cosmic bodies are invariable, the time elapsing between two successive eclipses should also be constant. Römer's observation did not confirm this assumption. If the Earth were as close to Jupiter as it can come in its orbit, and if both the planets were stationary, these eclipses should occur at exactly equal intervals, let us say, of one day and eighteen hours. If the Earth were immediately after the eclipse to rush over to the opposite point of its orbit, the next eclipse, which, of course, would follow again within one day and eighteen hours, should be apparently delayed by the time which the light requires to pass across the diameter of the Earth's orbit. That would be an average 997 seconds. Römer found a much higher figure, 1320 seconds. Now the earth of course does not describe one half of its orbit in so short a time as one day and eighteen hours; in fact during that half-orbit 105 eclipses are taking place, because the Earth is moving all the time, and we have to add eleven more eclipses on account of the movement of Jupiter. But the time interval remains the same. From his observations and the probable length of the axis of the Earth's orbit, Römer estimated the velocity of light at 313,000 km. per second. If, on the other hand, we could

determine the velocity of light upon the Earth, then we might calculate from this delayed occurrence of the eclipses the true diameter of the Earth's orbit. This has been done. The best-known determinations of the velocity of light have been made by Fizeau, Foucault, and Michelson. According to these determinations the velocity of light is 300,000 km. per second in empty space. The radius of the Earth's orbit should then be 149·5 million kilometers. Direct astronomical determinations have given almost the same figure.

Since the days of Laplace two great planets, Uranus (1781) and Neptune (1846), have been discovered, and further the many minor planets which are circulating between Mars and Jupiter (of which there are now about 600 known). The first one was detected by Piazzi on January 1, 1801, and called Ceres. They all move in the normal direction, anti-clockwise. Their orbits are inclined at different angles. The greatest inclination is 34·83°. The eccentricities of their orbits are also very different, the maximum being 0·383.

The double stars offer a particular interest. They have been studied with remarkable assiduity by W. Herschel, later by W. Struve, and recently by See. In several cases we have been able to determine the motion of these stars about their common centre of gravity; from that it became possible to calculate the eccentricity of their orbits. In quite recent time the study of stellar spectra has taught

us that a great many of the stars are moving to and fro. In their case as well it has been possible to determine the orbital eccentricities. These eccentricities are very different from those of the orbits of our planets, which are nearly circular. The eccentricities of stellar orbits range for the directly observed stars from 0·13 to 0·82, and their mean value is, according to See, 0·45. The spectroscopically studied double stars show smaller eccentricities. They range for 18 double stars, which are catalogued in Newcomb's "Treatise of Popular Astronomy," between 0 and 0·52, the mean value being 0·18.*

In the case of a few double stars we have succeeded in determining the masses of the two bodies. Taking the mass of our Sun as unit, we find: Alpha Centauri 1 and 1, Sirius 2·2 and 1, Procyon 3·8 and 0·8, the Star 70 in Ophiuchus 1·4 and 0·34, the Star 85 in Pegasus 2·1 and 1·2. We see from these figures that almost all these stars are larger than our Sun. The study of spectroscopic doubles has led to a similar result. In some instances the one of the two stars is too faintly luminous to be visible, and is hence called a dark companion. The variable star Algol which is occasionally obscured and partly covered by a dark companion offers a very peculiar example, in

* The more recent determinations by See fix the mean value of the eccentricities of the two classes of double stars at 0·50 and 0·22 respectively.

which the mass of the stars is relatively small. The diameter of Algol has been estimated at 2,130,000 km., that of its companion, at 1,700,000 km. Both are therefore considerably larger than the Sun, whose diameter is 1,391,000 km. Nevertheless the masses, as derived from their periods, do not appear to be more than 0·36 and 0·19 of the mass of the Sun. Their specific gravity is only 0·1 of that of the Sun. Another variable star, Z in Hercules, consists, according to the observations of Hartwig, of two giant suns which move about one another at a distance of 45 million km.; their diameters are 15 and 12 million km., their masses 174 and 94 times as large as the mass of the Sun, and their specific gravities 0·138 and 0·146. It looks strange that the smaller, dark body should have almost as small a density as the larger star; but a similar relation holds for the densities of our Sun and the large planets. The double star U in Pegasus has according to Myers a mean density of about 0·3 of that of the Sun. Roberts estimated the double star V in Puppis as having a mass 348 times as large as that of the Sun, but only one-fiftieth of its density. Myers also calculates for the well-known variable star Beta in the Lyre a 30 times larger mass, but a 1600 times smaller specific gravity than for the Sun. Although these calculations cannot be called reliable, they yet prove distinctly that our Sun is, as to size, a relatively small star,

but that it has already attained a very high degree of density, and should hence be in a relatively advanced stage of evolution. That it is only a faintly luminous star, we understand, when we inquire into the distance of the stars. At the distance of Arcturus or Beteigeuze the Sun would no longer be visible to the naked eye, and at a distance which corresponds to the average distance of the stars of the first magnitude, our Sun would appear to us like a star of the fifth magnitude, that is to say, it would rank with the just barely visible stars.

The relatively unimportant position of our Sun is no doubt partly to be explained upon the ground that it is the largest and most splendid of the stars which have been studied. Kapteyn has attempted to effect a kind of compromise by calculating how many stars of different brightness, taking the brightness of our Sun as unit 1, would be found in a sphere of a radius of 560 light years, whose centre is the Sun. The following is the result :

1	star has a brightness of more than	10,000		
26	stars have a brightness between	10,000	and	1000
1300	,, ,, ,, ,,	1000	,,	100
22,000	,, ,, ,, ,,	100	,,	10
140,000	,, ,, ,, ,,	10	,,	1
430,000	,, ,, ,, ,,	1	,,	0·1
650,000	,, ,, ,, ,,	0·1	,,	0·01.

We notice in this table that a strong increase in the number of stars is accompanied by a decrease

in the light intensity. We may therefore assume that the dark cosmic bodies will by far exceed the number of bright ones. They need not necessarily be of lesser mass for all that, although we must suppose that the brightest stars will also possess great volumes and therefore great masses ; their densities might yet be very small owing to their high temperatures.

The circumstance that the orbits of double stars appear to be of remarkably high eccentricity, by contrast to those of the planets, has been quoted in support of the assertion that the grand regularity of our planetary system must constitute an exception. This is not a forcible proof at all. The nebulous revolving disc resulting from the collision between two stars constitutes in general only a small portion of the whole mass. The largest part remains in the central body. A large portion of the matter outside the central body is dispersed into space by virtue of the velocity of the ejected particles. Some of the most rapidly oscillating molecules also escape, whilst the rotating disc is constantly becoming enlarged owing to the absorption of radiation from space. If now a strange body drifts into this revolving disc from space, two cases may arise. When the mass of this body, e.g. comet, is relatively small, the disc may force it to take part in its rotational movement. A planet would be formed, and it would move in a nearly circular orbit and in the plane of the disc. But

when the immigrating body has a mass which is large by comparison with that of the disc, the latter might yet be able to diminish the velocity of the former to such an extent that it would not be able to escape again from the central body of the nebula. The matter in the disc could only slightly modify its orbit, and this orbit would consequently become very strongly eccentric and might take place at any inclination towards the plane of the disc. This latter case was precisely that of the actual comets in the solar system according to Laplace. As now in the former instance the mass of the newly formed planet is relatively small, it would rapidly lose the small amount of luminosity with which it was endowed, and it would not be directly visible. Owing to its small size its influence upon the movement of the bright central body would further be very small, and the oscillating movement impressed upon the latter much too unimportant to enable us to draw any conclusions with regard to the presence of a dark companion. These instances would probably be more frequent than those in which a big cosmic body is caught; if only for the reason that the small celestial bodies, e.g. the comets, are relatively so common. They abound like the fish in the sea, says Kepler. Most of the large bodies of the Universe would be able to force their way through the nebulous masses without suffering a noteworthy reduction of speed

which would impede their further wanderings through space. Normal cases of this type would rarely fall under our observation. Where a large celestial body enters as a component into a double star under formation, the already existent planets would probably assume very complicated orbits.

W. Wien's law of the displacement of the wave-length of maximum energy with changes of temperature has also been applied for the determination of stellar temperatures. Very rigorous care must be exercised in these attempts. For the star light that we see is not the total radiation of the star, but a light that has been weakened by absorption in its outer atmosphere (compare "Worlds in the Making," page 71).

The temperature of a star may further be deduced from the intensity of its spectrum lines. Certain lines of the absorption spectra of gases are intensified with rising temperature, others are correspondingly weakened. Hale and his collaborators on Mount Wilson in California have investigated the spectra of metals which they evaporated in two series of experiments in arcs of 110 volts, both of 2 amperes and of 30 amperes. The second arc was naturally warmer (still hotter is the electric spark passing between metallic point electrodes of the respective metals), and thus they could investigate the changes in the spectrum lines caused by a rise of temperature. Comparing two spectra they would thus be able to

say, which of them belonged to a higher temperature, and they could judge whether, for instance, the light of a star or of a sun-spot suggested a higher or lower temperature than that of the solar disc. Hale concluded that the gases which absorb the light of solar spots have a lower temperature than those which absorb the light of the solar disc. This is due, no doubt, to the great density of the gaseous masses situated above the sun-spots; but it does not prove that the radiating bottom of the spot has a lower temperature than the clouds of the photosphere which radiate the light of the solar disc. By such comparative studies it has been demonstrated in Hale's laboratory, that the spectrum of Arcturus and the spectrum of Beteigeuze deviate in the same manner from the solar spectrum as the light of the sun-spots does. We may hence conclude that the absorbing gases in these immense stars, and especially in Beteigeuze, have a lower temperature than those above the solar photosphere. But the radiating strata need not for all that be colder in those stars than in the Sun. It appears, on the contrary, probable, that the lower temperatures of the outer layers of gas are due to the greater density of the absorbing gaseous medium.

The tidal phenomena, which G. H. Darwin has studied in a classical research, have exercised a great influence upon the development of the planetary system. Darwin shows that in all

probability the Moon just after separating from the Earth kept pretty close to it, and that the whole system completed one revolution within a little less than four hours. The tides, which were extraordinarily intense under these circumstances, gradually increased this rotational period of the terrestrial system, and the lost energy of rotation was partly expended in lifting the Moon slowly away from the Earth to its present distance. A similar tidal effect was exercised by the Sun upon the planets in the first stage of their development when they still had very large diameters; for the intensity of this effect is proportional to the third power of the diameter.

By these means the rotational velocities of the Sun as well as of the planets were diminished, and their distances from the Sun were altered. Darwin explains the peculiar observation, that the period of one of the moons of Mars, Phobos, is shorter than Mars' own period, by assuming, in accordance with Laplace, that Mars must originally have had a shorter period than Phobos. The tides caused by the Sun lengthened the period of Mars, so that it is now, with 24 hours and 37 minutes, much longer than the period of Phobos, which occupies 7 hours and 39 minutes.

It is similar with the ring of Saturn. The masses of dust nearest to the planet have a rotation period of 5 or 6 hours, whilst the period of the planet itself is 10¼ hours. In view of the very great

distance of Saturn from the Sun it is generally conceded, however, that the explanation cannot be given on the lines which apply to Mars. But would it not be possible that the matter in the innermost ring of Saturn might have approached its planet and thereby increased its rotational velocity? Something of that kind might occur owing to friction between the matter in the ring and a small portion of the planetary atmosphere. Laplace made such a suggestion, and C. Wolf shares this opinion.

We have pointed out one of the objections to the hypothesis of Laplace which equally applies to that of Kant, that the directions of the rotation of the planets should be the opposite to that of the Sun. All the planetary movements should be retrograde. Pickering assumes that all planets actually did start with a retrograde movement,* but that they lost it by the tidal action of the Sun, the result being that they finally always turned the same side towards the Sun, that is to say, that they assumed a normal rotation, equal in period to that of their orbital movement. By virtue of the subsequent contraction their rotations were again accelerated. The two outermost planets, Neptune and Uranus, are so far away that the Sun did

* According to the views which have been set forth in this book the original direction of a planet's rotation was not subject to any regularity and depended upon the direction of motion in the original nucleus of condensation which came in from outside.

not exercise any sensible tidal influence upon them during the period of contraction. As their mass amounts only to about one-sixth of that of the next planet Saturn, they must have cooled much more rapidly than the latter. These planets could therefore deviate from the general rule. As regards Saturn, the first nine moons are normal, the ninth being Japetus, which is nearly 3·5 million km. from it. The tenth moon, Phœbe, discovered by Pickering, is 3·5 times further removed and is retrograde. Pickering thinks that it may have been formed at a time when Saturn itself was still retrograde. Considering its great eccentricity (0·22), we should more probably liken Phœbe to the comets of the planetary system; it may only have come within the range of Saturn's attraction when the nebulous matter of this region had become greatly attenuated. Similar conclusions may be drawn as regards the outermost known (eighth) satellite of Jupiter. All the inner planetary satellites behave regularly.

Most of the discoveries which we have discussed in this section concern cosmic bodies situated outside our solar system. It was only after the introduction of powerful telescopes and particularly with the aid of the spectroscope (since 1859) that we succeeded in gaining a deeper insight into the peculiarities of these far-remote structures. Yet four hundred years before the beginning of our era Demokritos had taught that the stars in

the Milky Way resembled our Sun, and at the dawn of the modern age Giordano Bruno had dreamt of planets which were wandering about fixed star-suns. They were possessed by the conviction which guides the scientist in all his researches, that the relatively unknown will in its essential features resemble that which is near to us and which we have been able to study more closely. Experience has proved that Demokritos and Bruno were in the right, and that this principle of natural science will on the whole lead us to correct conclusions. The stars will be like our Sun, some smaller, some larger, some colder, some hotter than our great star.

Herschel found that some of the nebulæ which he examined were different from the Sun as regards light and extension. Spectrum analysis has corroborated him. Those nebulæ consist of widely spread attenuated masses of gas of a kind that we do not meet in our solar system. But by examining them and comparing them with other similar structures, he discovered a series of intermediate types between nebulæ and suns, and he concluded that these various forms represent different stages in the evolution and transformation of the Universe.

It was on this base that Laplace placed his famous hypothesis of the origin of the solar system. The extraordinarily manifold wealth of subsequent observations has entirely supported Herschel

in all his essential points and has at the same time elucidated our ideas concerning the character of the cosmic bodies.

No doubt we are even now only in possession of the very first rudiments of a knowledge of the stellar world, and we must still content ourselves with believing, together with Demokritos, Bruno, Herschel, and Laplace, that the yet unexplored regions of space will in the main resemble those which we have succeeded in examining by the aid of more perfect instruments. It appears in the highest degree probable that the future, with its deeper insight, will not differ as to essential facts, while ideas may take new and bolder flights of which the present generation knows nothing. Our knowledge will continue to improve, and the opinions of the scientist of past generations will undergo a further logical development. The superficial observer often gains the impression, that one system of ideas implies the subversion of the others, and it is often our lot to hear from those, who are not students of natural science, that all our endeavours to gain clear conceptions are wholly in vain. Whoever follows the course of evolution with some care will find to his great satisfaction, that our knowledge is growing like a strong tree from unpretentious seed, and he will always recognise the further growth and development of the same tree, although every part and especially the external clothing of leaves may con-

tinuously be renewed. The tree and the leading ideas have survived. Those ideas have remained unchanged in spite of the changes which circumstances have undergone in the course of hundreds and thousands of years.

VIII

THE ENERGY CONCEPTION IN COSMOGONY

IN concluding his classical work on the stability of the solar system to his own satisfaction Laplace gave expression to the hope that the Sun would continue to emit its life-spending light to our planets for indefinite periods. The conditions within the solar system would remain fairly unchanged for ever. The great astronomer felt no more called upon to offer an explanation for the continuity of the intense solar radiation, than his perhaps still greater contemporary Herschel had done.

That, however this inquiry into the cause of solar heat and of the glow of the stars was well worth examination did not escape the attention of Anaxagoras, who thought that the stars became incandescent by friction with the æther. Leibniz and Kant expressed the opinion that the solar heat was sustained by combustion, and the same idea of finding a solution for the heat problem is implied in Buffon's remarkable calculations upon the time which the planets had

required for cooling down from incandescence. Laplace too assumed that the matter, from which the planets had originated, must first have been in a state of incandescence and have subsequently cooled.

But it was only when the mechanical theory of heat started on its victorious course through the different domains of science in the middle of the last century that a firm basis for such considerations was found. The mechanical theory of heat teaches that energy is as indestructible as matter. The amount of matter had tacitly been accepted as invariable by all, who had meditated on cosmic problems, although the demonstration was only given by Lavoisier at the end of the eighteenth century. The introduction of the conception of energy dates from the past century.

If the Sun sends out its life-giving rays into infinite space, it must in some way be able to make up for the loss of energy, or it must cool rapidly. The latter assumption is disputed by geologists, who maintain that the solar heat has been radiated upon the Earth at an approximately constant rate for nearly a milliard of years. Robert Julius Mayer first attempted to find a source for this energy in the inrush of the meteors; Helmholtz improved this idea of Mayer's. Helmholtz thought that every particle of the Sun must slowly sink towards the centre and thereby engender heat. This solution of the problem was

generally regarded as the best and most satisfactory; but the recent investigations of geologists have more and more clearly established that this source could not be sufficient (compare Chapter III of "Worlds in the Making").

As the behaviour of substances, and especially the qualities of gases and their changes with varying temperature and pressure, became better understood, the dependency of the temperature of cosmic bodies upon changes in their volume, as well as upon the supply or loss of energy by absorbed or emitted radiation, was more thoroughly investigated. The most remarkable of these inquiries has been supplied by Ritter; we shall presently deal with it.

The utilisation of our knowledge concerning the influence of temperature upon the chemical reactions, that may possibly occur between the different constituents of a cosmic body, is now promising to come to our aid in these speculations regarding the purely physical changes in those bodies due to temperature and gravitation. Very probably these investigations will help us to a safe way out of the difficulty in which Helmholtz left us, when he confined his consideration to the relatively small amount of energy which is being liberated by purely physical processes, disregarding the far more powerful sources of energy in chemical reactions. This discussion will be carried further in the next chapter.

The remarkably comprehensive researches and deductions of A. Ritter just mentioned will exemplify how far we can proceed when we apply the laws of gravitation and of the indestructibility of energy to physical processes. Ritter starts from these two principles and presumes further the validity of the ordinary gas laws, whilst he assigns a secondary importance to heat conduction and to heat radiation. Similar inquiries had been published, eight years before, in 1870, by Lane. Later on Lord Kelvin, See, and especially Dr. Emden (1907) supplied valuable contributions towards the solution of this problem. The latter deals with the subject in a grand mathematical treatise which will be of great value for future workers in this field. In physical respects he does not go much beyond Ritter. The influence of radiation has recently been studied by Schwarzschild. We will in this place confine ourselves to the chief results of Ritter's exposition.

According to Ritter a mass of gas which obeys his laws will in general have an outer limit at which the temperature will be down to absolute zero. If we start from that border, the temperature will increase towards the interior and will at every spot be exactly that of a mass of gas that would have fallen from the limit down to this point. The matter will better be understood if we take the terrestrial atmosphere for exemplifica-

tion. Let the temperature on the Earth's surface be 16° C. (289 degrees upon the absolute scale), which actually seems to be the average temperature of our surface, then, according to Ritter, the height of the atmosphere would amount to 28·9 km. For, when one kilogramme of water falls through one kilometre, its temperature will be increased by $\frac{1000}{426}=2\cdot35°$ C. Since now the specific heat of air is 0·235, the same quantity of heat, which would raise the temperature of one kilogramme of water by 0·235°, would be able to raise the temperature of one kilogramme of air by one degree. A kilogramme of air falling through one kilometre would hence become warmer by 10°. (In this calculation we follow Ritter, who takes the specific heat of air at constant pressure.) In order now that the temperature of the air should rise by 289° above absolute zero, it should fall through 28·9 km., and that would be the height of our atmosphere.

If our atmosphere consisted of hydrogen, whose specific heat is 3·42, the atmosphere would attain a height of 421 km. The atmosphere would also reach up to a very considerable height, if it consisted of saturated water vapour and small drops of water suspended in it. To raise the temperature of that mixture by one degree, we should have to heat, not the steam only, but to supply heat for the evaporation of the water. The result would be the same as if the specific heat of the

mixture were relatively high. Ritter calculates that the height of an atmosphere consisting of water vapour should be 350 km., starting from a surface temperature of 0°. Now we know, that the air really contains some water vapour and clouds in addition to the less condensable gases. For this reason we add 2 km. to the height of 28·9 km. at which we had just arrived.

The resulting value does not at all accord with the usually accepted figures, as Ritter has himself pointed out. Shooting stars, observations prove, frequently flash up at an altitude of more than 200 km. above the surface of the Earth. There must hence be sufficient air and oxygen at that altitude to cause friction and combustion. The arcs of the northern lights, which we explain as electric discharge phenomena, have their highest points at an altitude of about 400 km. Observations made in balloons within recent years show that at a height of a little more than 10 km. the temperature becomes nearly uniform; it does not continue to decrease, while it decreases by about 10 degrees per km. in the lower strata.*

Ritter finds the explanation of this deviation from his deduction in the fact, that the gases of the air are condensed to clouds at very great heights, just as water vapour is condensed in the

* This so-called isothermal layer is found near the equator at an altitude of more than 20 km., in central Europe at an altitude of 11 or 12 km., and in latitude 70° at 8 km. altitude.

lower atmospheric strata. The height of the atmosphere should then be considerably increased.*

From what we know at present this condensation of oxygen and nitrogen cannot take place when the temperature exceeds $-200°$; that would be met at a considerably higher altitude than that which balloons have hitherto reached and in which the temperature gradient vanished. Meteorologists differ as to the explanation of these phenomena. I myself am inclined to believe, that heat radiation and heat absorption by the carbon dioxide and the water vapour in the air, possibly also by the ozone, play an important part in these processes.

Ritter calculates further, what would be the temperature of the centre of the Earth, if we were able to drive a wide air-shaft right through the Earth. He does not forget to consider that gravitation would change with the depth of the shaft, becoming zero at the centre of the Earth. Allowing for this he deduces for the centre of the shaft a temperature of about 32,000°. The temperature of the Earth at the centre should, according to other calculations, be about 100,000°. From these estimates we can form an idea as to the temperature rise in the interior of gaseous cosmic

* Goldhammer has calculated that the atmospheric height would be 62 km. for nitrogen and a little more than 70 km. for oxygen.

bodies. In so far as the Earth at the depth of 400 km. is pretty certainly gaseous, Ritter's calculations may have a certain justification in this instance. The specific heat of the gases confined in the Earth will, however, no doubt be much greater than the value Ritter assumed for his gases. That would lower the calculated temperature of the centre of the Earth. If we take into consideration the possibility of chemical reactions, the estimate may have to be reduced by more than one half, perhaps to one or two tenths. The pressure at this depth may be estimated at something like three million atmospheres.

We can now return to our consideration of the Sun. Gravitation is in the outer strata of the Sun about 27·4 times greater than upon the Earth. The temperature would therefore increase by about 274° per km., if the solar atmosphere consisted of air. But that atmosphere contains chiefly the gas hydrogen dissociated into atoms, while on our Earth hydrogen occurs in the molecular state, each molecule consisting of two atoms. The specific heat of mon-atomic hydrogen, at the temperature which prevails there, may be estimated at about 10, that is to say, 42·5 times as high as that of the air at freezing point. In the highest gaseous strata of the Sun the temperature would therefore vary by about 6·5 degrees per km. Since now the temperature of the luminous solar clouds has been estimated at 7500 degrees,

the solar atmosphere above them should attain a height of some 1200 km. Yet the pressure in this atmosphere does not, according to Jewell's research on the position of the absorption lines, exceed five or six atmospheres. On the Earth the pressure would be about 27·4 times smaller, i.e. about 0·20 atmospheres. The mass of gas situated above the luminous solar clouds would then not be greater than the mass of air above 12 km. altitude, where only the highest cirrus clouds are floating.

The thickness of the so-called chromosphere of the Sun has been determined during solar eclipses. It is the depth of the layer of gas which shines in the peculiar pink colour characteristic of hydrogen; this depth has been averaged at 8000 km., and that is more than six times as much as the value just mentioned. We hence come to the same conclusion as with respect to the Earth, viz.: that the atmosphere must be many times higher than it would be according to Ritter's deductions.

It would moreover be incorrect to assume that the temperature would sink down to 0° or still lower in the outer strata of the solar atmosphere. The radiation is far too strong there to permit of so intense a cooling effect. There are no doubt many condensed particles in these regions of the solar atmosphere; we conclude this from the weakening of the Sun's light as we go outward from the solar limb, when the light has to pass through

the higher strata. These particles or drops are heated by solar radiation and they impart their own high temperature to the surrounding gas. It is the same thing as in our own atmosphere, where the many dust particles absorb the solar radiation, assuming a temperature of 50° or 60° which they then communicate to the surrounding gases. In both cases the decrease of temperature with increasing height would be slower than Ritter considered, and for that reason the atmosphere would again be many times higher than Ritter's estimate.

We come back to Ritter's research. He has calculated, how pressure, temperature and density should change with the depths in a gaseous, spherical nebula. I have reproduced these calculations as modified by Schuster in "Worlds in the Making," page 198. According to these calculations the temperature in the centre of the Sun, if it consisted of atomic hydrogen gas, would be 25 million degrees, the pressure 8·5000 million atmospheres, and the specific gravity 8·5 (water equal 1). The table which is given on the page quoted practically shows only that, if the Sun were to expand to a nebula of ten times its actual radius, the temperature at the centre of this nebula would be 2·5 million degrees. But the contraction to the present size of the Sun would increase the force of gravity in the ratio of 1 to 100, and the temperature gradient per km. would

rise in the same ratio. Since, however, the radius has been reduced to one-tenth of its original dimension, the temperature at the centre of the mass would be one hundred tenths of its old value, that is to say, ten times higher than in the nebula. That applies for every other point of the Sun, and the temperature increase consequent upon contraction would be inversely proportional to the solar radius. On the other hand, the gases of the Sun, owing to their strong compression, would certainly no longer obey the simple gas laws, and for that reason Ritter's temperature estimate must be diminished. Assuming the Sun to consist of iron in the gaseous state, Ritter would arrive at a temperature of 1375 million degrees. The exceedingly high temperature would give rise to energetically heat-absorbing chemical processes which would again produce a strong reduction of the temperature. We finally come to an average solar temperature of something like 10 million degrees.*

When a mass of gas, such as the nebula under consideration, contracts, its temperature increases as was pointed out, and this increase is obtained at the expenditure of a great quantity of the heat which, in Helmholtz's opinion, would be liberated by the contraction. If there were no chemical processes, we should have to allow 81 per cent of the above-mentioned figure for heating, and only

* Ekholm indeed finds the lower value of 5·4 million degrees.

19 per cent would remain for radiation. In this part Ritter reckons with bi-atomic hydrogen, H_2; in the case of mon-atomic hydrogen, H, we should have to allow 50 per cent for radiation. Under these circumstances the Sun could not maintain its actual radiation for more than 5 (respectively 12) million years. The solar radiation must already have diminished considerably during the past ages. Ritter was well aware that the geologists demand very much longer periods for the existence of life on the Earth. Like most physicists he was convinced that the source of solar heat assumed by Helmholtz was by far the most important, and he did not attach much weight to the conclusions of the geologists. Later investigations have, however, further strengthened the arguments of geologists in favour of a higher age of our Earth and of a more invariable radiation of the Sun. Both van't Hoff's researches on the temperature which must have prevailed during the formation of the immense salt deposits in the different geological periods, as well as the geographical distribution of coral reefs in those ages, prove that the temperature of the Earth's surface, and consequently the intensity of solar radiation, cannot much have changed since these remote ages.

We are therefore forced to search for a source of heat, which will be both greater and less variable than the one considered, which is based

on the contraction of the Sun. Such a source of heat we find, no doubt, in the chemical reactions which take place during the slow cooling of the Sun. Those reactions would take place in the opposite sense during the contraction of the solar nebula, and it would hence result that the contraction of the Sun must have been still more rapid than Ritter assumed. Supposing that the radiation remained constant, scarcely a million years would be required for the cooling of the nebula reckoning from the time of the collision. During the time that the Sun was still in a nebular stage, it must, however, have stored up enormous quantities of energy by the absorption of radiant heat from outside. This energy, later on, when its own mean temperature commenced to fall, was spent in replenishing the losses of heat. Thus the temperature, and hence the extension of the Sun and its radiation, may have kept fairly constant for long periods. We also conclude from this consideration that the nebular stage lasted a much longer time than Ritter assumed.

Ritter carried his calculations further under the hypothesis that the height of an atmosphere over a body resembling our Earth, that is to say, a body provided with a solid crust, would be sufficiently great to force us to admit different values of gravitation at different heights. He found that, if the temperature of the solid surface exceeded a certain value, the atmosphere of such

a cosmic body would have no limit ; gases would indeed escape from it. Carrying out this calculation for hydrogen, he ascertained that the Moon would only then be able to keep an atmosphere of hydrogen, if its temperature always remained below —85°. But the temperature of the Moon is nearly that of the Earth on average, rising to 150 degrees in the hottest parts. We cannot then credit the Moon with an atmosphere of hydrogen. In the same way Ritter proves that the Moon cannot have any water on its surface. The same argument would apply all the more forcibly to the asteroids, which are so much smaller than the Moon.

These speculations of Ritter have attracted many scientists, among whom Johnstone Stoney and G. H. Bryan are the most prominent. Both start from the laws of the mechanical theory of gases concerning the free movements of the molecule. According to Stoney the Earth would be unable to retain hydrogen gas in its atmosphere, and that is probably right. But helium too would in his opinion be endowed with far too high a kinetic energy to be retained by so small a body as the Earth. The calculation does not appear to favour Stoney's view. But we may imagine that helium had already left the terrestrial atmosphere at a very early period, when the temperature was much higher and its extension much greater.

Ritter's inquiry into the effects of a collision is of very great interest. Mayer had shown that a meteor, rushing into the Sun from a very great distance, for instance, from the distance of Neptune, and starting with an initial velocity of zero, would at the Sun's surface have attained a velocity of 618 km. per second, and would therefore increase the solar energy by 45 million calories per gramme of its (the meteor's) mass. In the collision between two suns an immense quantity of heat must necessarily be liberated. That heat may be spent in expanding the new body. If two equal suns were to rush against one another from infinite distance, likewise starting from rest without any initial velocities, the heat produced by their collision would according to Ritter suffice to expand the two masses of gas to four times their original volume. In order that the whole masses of the two colliding suns may be spread over infinite space, each of them should have an initial velocity of about 380 km. per second. Such a velocity sounds very great for what we call a fixed star. This speed would, however, appear to be surpassed by a small star of the eighth magnitude discovered by Kapteyn in the constellation Columba. This star is credited with a velocity exceeding 800 km. per second, and the giant sun Arcturus seems to move with a velocity of 400 km. per second. All the same, these high velocities may be very rare exceptions. But a

sun of a hundred times the dimensions of ours, colliding with a gas ball of similar dimensions, would only need an initial velocity of 38 km. per second in order to disperse its whole mass throughout infinite space, and to form what Ritter calls a "centrifugal nebula," which would continue to expand and to spread out further and further into space. "We may perhaps class the spiral nebulæ, due to oblique impacts, with the centrifugal systems." Strictly speaking the expansion would go on unlimited in all directions. But the gases might conceivably be checked and arrested in their movements and stopped by meeting material particles. Ring-shaped nebulæ might be formed in similar ways. Croll had required velocities of over 700 km. per second for two colliding suns in order to explain the production of solar heat; Ritter did not think that necessary. We may also lay stress upon the statement, that a gaseous nebula of the mass of the Sun and of a hundred times its radius without colliding with another cosmic body, merely by its own contraction to the dimensions of our Sun, might acquire a sufficiently high temperature to make it shine as a bright white star.

When the velocity with which the two cosmic bodies collide sinks below the value above stated, a centripetal system would arise, that is to say, a mass of gas which would gradually contract to a fixed star. According to Ritter this star might

periodically swell and contract as if oscillating about a position of equilibrium; in this way he seeks to account for the periodical fluctuations in the light intensity of variable stars. Such pulsating movements would soon be checked, however, by radiation; the changes in the light intensity of such stars, moreover, are not, as a rule, so regular as Ritter's calculations assumed. His view on this point has not met with general acceptance.

Ritter further believes that condensations into small stars take place in centrifugal systems. The condensation would lead to the formation of star clusters, and we have indeed reason to suppose that the spiral nebulæ consist to a large extent of such star clusters. Finally Ritter raises the question, whether the Milky Way might not possibly be such a star cluster originating from a centrifugal system. He says, however, that in that case the system of the Milky Way could not possibly make up the main bulk of the material in its immediate surroundings.

In order to attain so high an initial velocity, as would explain the formation of a centrifugal system by a collision, the two colliding masses of gas should, in his opinion, previously have been exposed to the attraction of still greater masses, and these forces should have continued to act.

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Ritter thus concludes that centrifugal systems would only in rare exceptions result from the

collisions of two extinct stars, the condition being that the suns move at an extraordinarily high velocity. Nothing prevents us from assuming, however, that a comparatively small fraction of the solar system may be centrifugal, whilst the main mass is a centripetal system. The combination would be normal, as has been indicated above. The centrifugal system would form a spiral nebula about the centripetal as centre, and the latter would gradually be evolved in the manner which Laplace suggested for the nebula which became transformed into the planetary system.

Ritter has also calculated the periods which a fixed star of the size of our Sun would require for the different stages of its development. He distinguishes four periods. His first period is that of the nebular stage. The temperature is relatively low, the star shows first the nebular spectrum; afterwards it emits a reddish light. Several scientists, as, for example, Lockyer, incline to this view for theoretical reasons; but observations do not support it. The nebulæ show the bright lines of hydrogen and helium. But many stars give the same bright lines and should therefore be closely related to the nebulæ; they emit, however, a white, not a red light. It would, therefore, appear that the intermediate stage demanded by Ritter between nebulæ and white stars, i.e. nebular stars with red light, is missing. But it

may also be that such transitory stages, if extant, are very rare (compare "Worlds in the Making," page 185). Ritter, moreover, considers these intermediate stages as of insignificantly short duration by comparison with the period required for the transition from white to the red light.—There are many red stars of very high intensity, Beteigeuze, for instance; the red light of this star is presumably due to the absorption of light by the dust in its atmosphere or in its surroundings (compare "Worlds in the Making," pages 71 and 181).—The first period up to the maximum of radiation would comprise a space of 16 million years. The temperature afterwards rises—not sufficiently, however, to raise the total radiation at the same time, because the radiating surface is rapidly becoming smaller—until it reaches its maximum. This period is relatively short, about 4 million years only. The third period, during which the light intensity of the star is continuously diminishing and its temperature falling, may last some 38 millions. Then would finally follow the fourth period of very long duration, the lightless, extinct stage of the star. All these calculations are based upon the assumption that the heat of the Sun is merely due to its contraction, and they may, therefore, be altogether wide of the mark, because probably it is the chemical processes, and not the contraction, which constitute the chief source of heat.

Ritter's calculations lead to the result that a sun cannot be awakened to a new life by collision with a planet if the sun is itself already extinct. Kant's poetical dream of the revival of the solar system by the rush of the planets into the Sun can hardly be realised. "The accumulation of incombustible and already burnt matter," the celebrated philosopher says, "e.g. of the ashes on the surface, finally also the want of air, will end the existence of the Sun; its flame must once cease to burn, and the spot which is at present the centre of light and of life for our Universe, will some day be taken up by eternal darkness. The alternating endeavours of its fire to revive itself by the opening up of new caverns, whereby it might be restored several times before its destruction, might afford an explanation of the disappearance and the reappearance of some fixed stars." "We must not wonder to recognise perishability even in the grand work of God. Everything that is finite, that has a beginning or an origin, bears the imprint of its own limited nature. It must perish and must come to an end. Newton, the great admirer of God's qualities from the perfection of His works, who combined with the deepest insight into the excellence of Nature the greatest reverence for the revelation of Divine omnipotence, felt constrained to predict to Nature her own decay by the natural tendency of the mechanics of motion." "In the infinite course of eternity there must finally be

a moment, when this gradual diminution will have exhausted all movement."

"We need not regard the destruction of one Universe as a real loss in Nature, however. In another spot this loss will be made up by abundance." Kant imagined that whilst the suns were vanishing in the neighbourhood of the central body of the Milky Way, new suns would be rekindled in the remote cosmic nebulæ, and the number of inhabited worlds would always be growing. But Kant did not like the idea that our Sun and planets would lie dead for all eternity in the centre of the Milky Way. That seemed to him to be incompatible with reasonable rule. "If, in conclusion, we may give expression to an idea, which seems as probable as it is appropriate for the constitution of the divine work, then the satisfaction which such a picture of the changes of Nature produces in us will be elevated to the highest state of contentment. May we not believe that Nature, which could bring itself into order and a suitable system out of chaos, will as easily be able once more to renew itself out of the new chaos, into which the diminution of its movements has sunk it, to restore the former combination? Cannot the springs, which first marshalled into order and movement the substance of dispersed matter, by the aid of renewed forces be set into motion again after the machinery has run down? We need not hesitate to admit this possibility, when

we consider that, when the final fatigue of the orbital movements will have made the planets and comets all rush into the Sun, the glow of the Sun will receive an immense accretion by the admixture of so many and so large lumps, especially because the most remote balls of our solar system contain, according to our deductions, the lightest and the most fiery substance of all Nature." The renewed supply of fresh fuel would make the Sun flare up once more in violent conflagration and suffice to bring everything back to its original state, so that a new planetary system could be formed from the new chaos. This cycle would be repeated several times. Then the greater system of which ours forms merely a fragment, the system of the Milky Way, would in itself be brought to rest, to be revived again and to impart new life to formerly void space.

"When we follow this Phœnix Nature, which cremates itself only to rise rejuvenated from its ashes, through the infinity of space and time, the mind which ponders over all these problems sinks into deepest wonder."

We did not know the mechanical theory of heat then, and Kant who dimly felt that the glow of the Sun must be sustained by combustion (chemical processes) did not recognise the inconsistency of the assumption that the burnt-out matter could again and again create new energy by repeated recombustions. It would be unjust

to measure by a physical scale this beautiful poem in which Kant even divested himself of his usual style of writing. Under the criticism of natural science the magnificent conception of Kant in which the longing for the eternity of Nature finds so nearly true an expression shrinks to nothing. It is the grandeur of his system which excites our admiration, not its physical foundation. To work out the details of his scheme was not given to Kant.

Kant's idea was adopted by the spiritistic philosopher Du Prel (1882), almost unchanged, and yet in lighter garb, which permitted him to take account of the enormous strides that our knowledge of the heavens had meanwhile made and to avoid the naive teleological sentiment of Kant. He too makes the planets rush into the extinct Sun to revive it again. "We cannot believe that the corpses of stars should, like icy spectres, float through space until reunited with the central system which would finally be reduced to immobility by the resistance of the æther. We shall rather regard the primary nebula from which the star clusters were formed as the product of the reunion of all the stars of a cluster, whose motions, converted into light and heat, produced a temperature at which the total matter was retransformed back into a nebula—a cycle which reminds us of those "Kalpas," by which the Buddhists designated successive periods in the existence of the Universe, counting millions of

years and separated from one another by destructions."

A closer examination convinces Du Prel, however, that the whole Universe cannot be at rest at the same time; the life which dies in one spot will be blossoming out in its most beautiful shape in another. "Like Penelope who undid at night, what her busy hands had woven during the day, Nature destroys at times its works, and we have no right to ascribe to Nature the intention of completing the texture."

"After the destruction the development of every star commences afresh, and from our standpoint of terrestrial intelligence, the deep night of total oblivion will cover everything that might in a general sense be designated as the history of the defunct stars. No different race, no creatures destined for something higher will once become the heirs of the Earth, and nothing of all that mankind has achieved, will pass over into the hands of other beings." In agreement with Mädler, Du Prel regards the Pleiades as the central system about which our Sun is circulating. This view has, however, hopelessly been refuted by the researches of A. F. Peters.

"Thus we find in the cosmos, in proximity, all the phases of that eternal transformation in which gravitational movement is converted into heat, and heat into movement in space. Here swarms of flaming worlds radiating in their fullest splen-

dour, there fading star clusters, in which the variable stars indicate the period of decay, and the darkened suns attempt by a last effort to guard off the icy death. Whilst in one region the first suns begin to germinate in well-defined nebulous spheres, the delicately organised solar systems are, in other spots, once more carried out into space in the shape of diffused masses of gas. And ever anew recommences the Sisyphus labour of Nature."

Du Prel introduces the Darwinian conception into the consideration of the development of nebulæ into planetary systems or star clusters. The spheres of our planetary system enjoy marvellous stability. Thanks to their almost concentric orbits they are not threatened by collisions. Those which were less favoured as regards their trajectories have been colliding with one another, either to form new bodies with more favourable orbits, or finally to rush into the Sun. In this way those planets were gradually eliminated whose trajectories did not exclude the possibility of collisions, and we arrive finally at the actual, so extraordinarily fit system, whose stability is so wonderful that Newton deemed it necessary to institute a reasonable Being who had arranged everything from the beginning. This exposition of Du Prel's reads very acceptably. But it is nothing more than Kant's conception clothed in a modern, very beautiful and pleasing garb.

Du Prel rediscovers his own view in Lucretius in the following remarkable verses of his: De natura rerum, I, 1021-1028,

"Nam certe neque consilio primordia rerum
ordine se suo quæque sagaci mente locarunt,
nec quos quæque darent motusque pepigere perfecto,
sed quia multa modis multis mutata per omne
ex infinito vexantur per cita plagis
omne genus motus et cœtus experiundo
tandem deveniunt in talis dispposituras,
qualibus hæc rerum constitit summa creata."

Which H. A. J. Munro has rendered:

For, verily not by design did the first beginnings of things station themselves each in its right place guided by keen intelligence, nor did they bargain sooth to say what motions each should assume; but because many in number and shifting about in many ways throughout the Universe they are driven and tormented by blows during infinite time past, after trying motions and unions of every kind, at length they fall into arrangements such as those out of which this our sum of things has been formed.

Roche has pointed out that, if the planets were some day to fall towards the Sun, because something checked their movement, as Kant and Du Prel imagined, they should, long before reaching the central body, be crushed by the unequal action of gravity upon the different parts—those near and those further removed—of the same planet. Biela's comet, e.g., was destroyed in this way when coming too near the Sun. During this annihilation violent

volcanic eruptions would no doubt raise fragments of the planet to a temporary incandescence, even if the Sun were already extinct. That glow would, however, be too faint to be noticed outside our planetary system. If the Sun were not extinct, the planet would doubtlessly melt into a fused mass of doughy consistency, from which pieces would separate without any violent disturbances. In any case the planet would finally descend quietly upon the Sun in the shape of meteoric dust, and there would be no change in the physical state of the Sun. We may admire the story of the creation according to Kant and Du Prel; but we cannot credit it with a physical foundation. Their system would have to be realised in other modes than those proposed by them.

IX

THE CONCEPTION OF INFINITY IN COSMOGONY

WHILE we have so far chiefly dwelt upon scientific problems, we turn now to the more philosophical question of the conception of infinity. A star like Sirius may be ever so far removed. There will be stars still further off, and when we at last think that one star must be the very last and most remote of all, we cannot but imagine the space beyond it to be continued. We cannot conceive a limit to space any more than a limit to time. However far back we may carry our ideas, we shall still be confronted by the thought, that there must have been a time before that particular moment. Nor can we conceive any end to time. Space is infinite, and time is eternal. But it is equally impossible to grasp the idea of infinite space and of infinite time. Hence man has attempted to picture the Universe as finite, and time as starting from a beginning. We remember the Babylonian creation myth.

The view that space might be finite, although

apparently infinite, has strangely enough found various and ingenious advocates, among others the great mathematician Riemann and the great physicist Helmholtz. The surface of the sea appears to us curved, because the Earth is a sphere, and of an island which is some miles distant we see from the opposite shore not the beach, but only the tops of the trees and the crests of the mountains. At times, however, peculiar atmospheric conditions occur under which the opposite shores become visible to us. If the atmosphere were throughout of the same density, the rays of light traversing it would be perfectly straight lines. But the density of the air increases from above downwards at a rapid rate, and light is refracted in the air almost as if it were passing through a prism. This increase of density in atmospheric strata may, under certain conditions, be such that a ray of light, which issues parallel to the surface of the Earth, is so refracted that it always remains parallel to it and assumes the curvature of the open sea. A person looking straight towards the horizon would in that case look right round the Earth, so to say, and be in a position to see his own back. The man would, of course, not be able to discover himself in this way; but the Earth or rather the sea would appear like a smooth plane extending to infinity in all directions.

We might now fancy that light rays, coming to

us from space, should also be curved for some reason or another, so that, while apparently gazing upward, we should be looking around the Earth and finally see objects really visible only from the other side of it. It would not be possible to us, it need hardly be pointed out, to see the Earth itself in this (false) line of sight; because the path which the light would have to describe on its way from the other side of the Earth up to our eye would be of immense length, longer than the distance of any visible star. Nor should we be able, as might easily be proved, to see any stars further removed from us than the extreme points of that circular path which the ray of light would have to describe.

Although we should therefore only see that portion of the Universe, which lay within a certain distance—very great indeed, but of a definite limited length—we should yet fancy that we were looking across the Earth in every direction, straight into infinite space. We could not hence assert that space was infinite, at least not so far as we relied upon our own perception.

Helmholtz wished that this possibility should be examined by astronomers. As our observations do not suggest anything of the kind, the examination appears to be rather superfluous. For we cannot imagine any cause which would vary the density and refractive power of the æther in space in the same manner, as tem-

perature may affect the density and the refractive power of our atmosphere so as to produce a curved ray. It seems unnatural to assume that the line of sight could gradually become curved in space. All these notions which excited considerable attention for some time after the middle of the last century have almost completely been abandoned, all the more so because the idea proved barren in scientific respects. People interested in this particular question will find critical reviews in the works of the Dane Kroman and of the American Stallo, as well of the French mathematician Poincaré. We are satisfied with the old, simple notion.

Whether or not the number of stars is infinite is an old controversy. Anaximandros, Demokritos, Swedenborg, and Kant regarded it as infinite. If the stars are to be fairly uniformly distributed in space and not strongly crowded there, where our Sun is placed, the whole sky would glow in the splendour of the stars, more intensely still perhaps than the Sun, and everything on the Earth would be burned. This conclusion was drawn by Olbers in 1826. (We assume that all the cosmic bodies would have the same average temperature as the fixed stars, which on the whole appear to be warmer than the Sun.) But the Earth is not being consumed by fire, and we have only two reasons to account for that. Firstly, the stars may be concentrated in the

immediate neighbourhood of our solar system and become the scarcer, the further away from it. It is strange that most astronomers are inclined to accept this very unphilosophical view. The demonstration of the radiation pressure has disposed of that notion. For owing to that pressure all the stars would in the infinite course of time have been dispersed through the infinity of space, if really they should ever have been concentrated about a certain centre, such as the middle of the Milky Way.

If this first argument is not valid, we have to consider the other possibility, that a great number of dark celestial bodies of extremely low temperature and immeasurably larger than the visible stars may be existent in space. The cold nebulæ are such bodies. They cover a very much greater portion of the sky than the fixed stars. The light which we receive from all the stars together amounts to one thirty-millionth part only of the light that the Sun sends us. If we assume equal brightness per unit area in the two cases, the area covered by all the fixed stars which we see would be less than 0·1 square second of arc. A big planetary nebula, No. 5 in W. Herschel's catalogue, situated near the star B in the Great Bear, has a diameter of about 160 seconds of arc, and covers consequently an area 260,000 times greater than that of all the fixed stars. In addition to the planetary nebulæ we have the irregular

nebulæ, e.g. that of Orion, which possess a very low density, but extremely large extension. It is on account of this prevalence that we ascribe so great an influence to the nebulæ. They possess the strange property of expanding and cooling by absorbing radiated heat from outside. When they expand, those molecules of gases which possess the greatest velocities are expelled and are replaced by masses of gases from the interior, more concentrated portions of the nebula. Under a diminution of entropy greater and greater masses of energy are in this way accumulated in these streams of gases which collect on neighbouring stars (compare "Worlds in the Making," page 191).

Thus there remains no other conclusion but that the number of stars in infinite space must be infinite. We are far removed yet from knowing even all those which are not obscured by other bodies that stand in our line of sight. The more our optical apparatus are perfected, the more new universes with crowds of stars open up to our eyes. But their number does not increase in the same ratio as the space which those instruments resolve. The ratio is far less, and that may partly be due to the obscuring action of the dark bodies.

That matter is imperishable or eternal was dimly felt by the primitive races in their creation myths. The original assumption was a chaos or primeval water which had been existent from all

eternity. Riper thought led then to the philosophical views of Demokritos and Empedokles. But during the Middle Ages metaphysical notions began to rule. Matter according to them originated from nothing by an act of creation. We meet with this idea in Descartes—though we are not certain of his believing in it—in the immortal Newton, still even in the great philosopher Kant, and much later in Faye and C. Wolf. Yet we can trace the leading idea of a gradual development of matter under constant preservation of its quantity through all cosmogonies. There is a strange inconsistency in the notion that the world could suddenly have begun to exist. We cannot expect that one single man should solve the whole totality of the cosmic problem, and we can very well understand, therefore, why Laplace should say, he only intended to demonstrate, how a certain portion of the development had taken place, and to leave the rest to other scientists. Instead of imposing upon themselves some such simple restriction, people have often jumped at supernatural explanations. They abandoned the clear rule of the constancy of the laws of Nature which Spinoza had laid down (page 48).*

* The great philosopher Spinoza was born in 1632 in Amsterdam, and he died at the Hague in 1677. His fate proves that civilisation has made enormous strides since that time. It may, therefore, be briefly related here. His parents were Portuguese Jews, whom the persecutions of the Inquisition had driven to Holland. The extraordinarily gifted young man could not

Herbert Spencer is equally clear on this point. He declared that we cannot believe the visible world to have either beginning or end. When Spencer said this, he knew the doctrine of the indestructibility of energy (it was called force then) quite well, and he was, of course, familiar with the thesis of the indestructibility of matter, which had been demonstrated by Lavoisier and which had tacitly been accepted before, although not clearly understood. During the last decades the question has been asked, whether matter (as determined by weight) might not be destroyed after all. With the utmost care, Landolt has conducted series of experiments upon the constancy of weight during the chemical reactions between two substances. He did in a few cases observe some insignificant variations of weight and apparent losses of matter, greater than the experimental errors. Continued experiments have, however, convinced him that those variations of weight were only apparent and to be explained by slow changes in the volume of his vessels due to a rise of temperature during the reactions. We are therefore experimentally justi-

refrain from questioning some religious dogmas of the Jews of his time, and he was therefore harshly dealt with by his fellow-believers. Finally they endeavoured to persuade him, under promise of compensation, to give apparent recognition to the Jewish tenets. The offer was refused with scorn. His life was then attempted, and he was expelled from the Jewish community. Afterwards he supported himself by grinding optical lenses while writing his grand philosophical works.

fied in saying: the manifold experiences of chemists entirely confirm the view of the old philosophers that matter is indestructible.

It is strange that learned men, who are ready to concede a sudden origin in dealing with cosmogonical problems, do not in their systems ascribe any time limit to matter. This inconsistency is really incomprehensible, as incomprehensible indeed as if we were boldly to assert that the stars to the north of the ecliptic were infinite in number, but not those to the south of it.

It might be objected that under certain circumstances physicists speak of infinity in one direction reckoning from a certain point, but not of a continuation of infinity in the opposite direction. Thus we count the degrees of temperature upwards from absolute zero, but we do not count any degrees below that point. The objection can be met. It would not be impossible at all to imagine a scale of temperature, which involved the assumption of a negative infinite temperature. It would be sufficient, for instance, to base statements of temperature upon the logarithms of temperatures reckoned from $-273°$. On the other hand we have to admit, that temperature is probably due to molecular movements, that a movement in the negative sense would be perfectly equivalent to a movement in a positive sense, and that it is for this reason impossible to go below absolute immobility. Nor can we any

better conceive negative matter. But a negative, that is to say, a past time, we cannot only conceive, but we must conceive it, and it is therefore quite inconsistent to speak of the eternity of matter in the future, but not of its eternity in the past.

Spencer has pointed out, as already mentioned, that it is just as impossible to imagine a creation of energy or force, as a creation of matter. "Force can neither arise out of nothing, nor lapse into nothing." On this point the philosophers had shadowy ideas to which the advance of natural science has given better expression. In the writings of Descartes, Buffon, Kant, as indeed in all older cosmogonies, we meet with many traces of a dark presentiment of the indestructibility of energy. Descartes and Kant insisted that to maintain the glow of the Sun some fire was necessary for whose sustenance the presence of air was regarded as indispensable. Buffon thought even that the other suns, which likewise emit heat continuously, sent to our Sun as much light as they take from it. He thus suggested a kind of thermal equilibrium. Unfortunately he did not examine the problem any further.

A clear insight into these relations was only given, at the beginning of the past century, by the genius of Sadi Carnot. But some of his work remained unedited and unknown owing to his untimely death, and the principle of the indes-

tructibility of energy had to be revived by Mayer, Joule and Colding, and to be worked out by Helmholtz. It is very significant that not one of these men was a scientist by profession, though Helmholtz was an eminent mathematical scholar. Carnot and Colding were engineers, Mayer and Helmholtz medical men, Joule a brewer. If we look more closely into the causes of the discovery, we find principally philosophical arguments, and sharp attacks have indeed been directed against these pioneers, because their views were too philosophical. Scientists had long held the opinion that heat was due to motion of the smallest material particles. Expressions to this effect we find in Descartes, Huygens, Lavoisier and Laplace, Rumford, and Davy. Another school regarded heat as one of the "imponderables." The founder of the mechanical theory of heat had in a certain sense already gained a clear grasp of the former assumption. But Carnot was chiefly interested in considerations concerning the nature of caloric engines, in which work is done by heat passing from a warm body to a cold body. In a transformation of heat, such that maximum work is performed, the quantity of work should in all cases, according to Carnot, be independent of the heat transferring medium, provided that the warm body and the cold body were all the time kept at the same temperature. This principle may also be

expressed by the statement, that the "perpetuum mobile" is impossible. In this phrase we recognise the firm conviction of the engineer that no work can be produced from nothing. Mayer's treatise teems with expressions such as: from nothing comes nothing; he had imbibed the idea of the substantiality of work. Colding wrote that it was his firm conviction that the forces of Nature, which we found here, as well in the organic, as in the inorganic world, in plants and animals as well as in lifeless Nature, had not only been in existence since the beginning of the world, but that these forces must always have been at work, in developing the world in the sense which was imparted to it at the creation. Joule says in a popular discourse: "We may conclude a priori that an absolute annihilation of the *vis viva* $\frac{mv^2}{2}$ cannot take place; for we cannot assume that the force with which God has endowed matter can be destroyed or can be created by human activity." Helmholtz's treatise which came four or five years later, is to-day regarded as a physical memoir of the first order. Then, however, the most prominent scientific journal, "Poggendorf's Annalen," refused to accept it, as it had declined to publish Mayer's treatise. We see plainly that the physical importance of these investigations was not understood. They were merely regarded as philosophical speculations. Those very researches have become the foundation of the extraordinary

reform which not only physics, but chemistry and physiology have undergone during the past century. The indestructibility of energy and its existence from eternity to eternity has been established once and for all.

Strangely enough the development of this branch of science carried with it the germ of the negation of the principle of eternity. The theory of heat postulated that heat should by itself, that is to say, as long as no work was being performed, always pass from the warmer to the colder body. As a consequence the development of the world would proceed in the sense that all energy would gradually be transformed into molecular movement, and that any temperature differences in the Universe would tend to equalise. That done, all motion must cease with the exception of the molecular movements, and all life must become extinct. That would be the complete Nirwana of which the Indian philosophers were dreaming. Clausius has designated this final state of thermal equilibrium "Wärmetod" (heat death). If the world really tended towards thermal extinction, we do not see why this fate should not have befallen the world already in the infinite ages through which it has manifestly passed. And since we convince ourselves every day, that the world has not yet been struck by this fate, we should consistently conclude, that the idea of eternity has no real basis, and that the world cannot have been

existent for unthinkable ages, but must have had a beginning, i.e. that it must have been created, and that the creation gave us both matter and energy. By his "degradation of energy" Lord Kelvin has lent his authoritative support to the doctrine of thermal extinction. Yet the doctrine implies the absolute negation of the idea of eternity which is the foundation of the mechanical theory of heat. We must look for some way out of this difficulty.

The Universe is undoubtedly passing through a development. If that development always took place in the same direction, it would finally come to an end. If an end is not attained, the reason can only be, that the development is not tending towards a final standstill, but that it involves a kind of cyclic movement. A hint of such a view, though very obscure indeed, is found in Kant. He speaks of the "renewal" of the burnt-out suns "in mixing with chaos" by expelling the finest and most volatile matter of the Sun into the Zodiacal Light, which he regards as a remnant of chaos.

We quote the following remarkable sentences from Kant. "If now creation is infinite with regard to space, the Universe will be alive with worlds without number and without end." Further on he discusses, how the suns have become extinct, how the worlds moving about the central body which he assumes to be in the visible Universe

will perish to be reawakened to life at far distances, so that the number of living worlds is constantly growing. "But what becomes of the matter of the destroyed worlds? May we not believe that Nature, which was once able to arrange herself to so fitting a system, might once more step forward and renew herself out of the new chaos in which the disappearance of all motion had immersed it? We shall no longer hesitate to admit this." Kant believes that when planets and comets are rushing into the Sun, matter is expelled by the heat thus created in all directions, and by the consumption of this heat a new planetary system will be formed resembling the old one. In a similar manner the immense system of the Milky Way will collapse some day and be restored. Such processes, he believes, may be repeated "to fill eternity as well as all infinite space with their wonders." This grand speculation unfortunately lacks a physical foundation (compare page 214). Croll suggested, in 1877, that the regeneration of the original nebula required the collision of two extinct suns. This path, which later scientists like Ritter, Kerz, Braun, Bickerton, and Ekholm have taken, leads us to the conclusion that the whole Universe tends to aggregate into one cold dark mass. If we are to escape this conclusion, we must look for forces which disperse matter.

Herbert Spencer (1864) is most precise on this point. His argument is the following: There is

a co-operation of forces in the development of planetary systems, forces which tend on the one side to collect matter and on the other side to disperse it. The collective forces predominate during that period of development which is characterised by the transformation of nebulæ into the suns, planets, and moons. Some day, however, the diffusive forces must gain the upper hand, and the planetary system will then return to the state of attenuated nebula from which it had grown. Long periods of collective forces will alternate with extensive periods in which the dispersive forces will predominate. When matter is collected, motion is dispersed, and when motion is absorbed, matter is dispersed. Rhythm characterises all movement. Spencer believed evidently that in the concentration of matter by virtue of the mutual approachment of the bodies potential energy was lost; by the diffusion of matter potential energy was stored up again—the inverse relation would apply for the energy of motion. Nietzsche has expressed himself in a similar way.

Spencer is certainly right in the main. But as the physicists of his time did not know any dispersive forces, such as Spencer postulated, his words remained unheeded. Those forces are well known now. They are chiefly accumulated in the explosive compounds which form in the innermost portions of the suns at highest pressures and temperatures. To this is to be added the heat

absorption by the dust contained in the thin gas envelopes during the nebular stage; by virtue of the accelerated molecular movements gases are expelled in all directions, and will finally augment the energy of the masses, especially of the stars, in their neighbourhood. This process counteracts the so-called increase of entropy, or with other words, the equalisation of temperature between different bodies of the Universe, and it delays the Wärmetod (compare "Worlds in the Making," pages 194–211). We have further the radiation pressure which carries the particles away from the suns through all space.

The new conception of the indestructibility of matter imposed upon natural scientists new problems to be solved. They had to ask themselves, how the Sun could waste its energy without, it seemed, becoming noticeably colder. Mayer gave the answer that the solar heat was maintained through the inrush of meteors into the Sun. That this source of energy would be entirely inadequate has already been pointed out at length (compare "Worlds in the Making," page 67). This holds also for the modification of Mayer's thesis given by Helmholtz, according to whom the whole mass of the Sun would sink towards the centre of the Sun, or that the Sun would become warm by contracting. This view of Helmholtz is still quoted in support of the theory of Laplace, according to which the Sun is the result of the contraction

of a vast nebula. We have already explained that on this supposition the Sun could not have been radiating heat at the present rate for more than 20 million years.

Geologists, however, would not listen to such estimates. They demanded for the deposition of the earliest Cambrian fossil-bearing strata something of the order of a hundred or a thousand million years, whilst perhaps 100,000 years must have passed since man first walked on the Earth. The demand led to a violent controversy between geologists, biologists, and physicists, especially in England, where several physicists sided with the geologists. The contest was, of course, decided in favour of the geologists, who had positive statements to rely upon, whilst their opponents chiefly brought up the negative argument, that they could not say where the Sun might under such circumstances have found the source of its energy.

I have endeavoured to elucidate this problem by pointing out that chemical reactions may liberate all the more heat, the higher the temperatures at which they proceed. Let us consider, for example, what will occur when the temperature of one gramme of ice is gradually raised from −10°. At the freezing point the ice will liquefy and will absorb about 80 calories. At 100° it will evaporate and absorb 540 calories. At still higher temperature, about 3,000°, water vapour will dissociate into hydrogen and oxygen, under a

further consumption of about 3,800 calories. Our experimental means then fail; we cannot produce any higher temperatures. But it would be wrong to assume that chemical processes must cease because our apparatus fails. It is very probable that at very high temperatures hydrogen and oxygen are split into their atoms under consumption of hundreds of thousands of calories. Now, it might be said, we have come to the end of the chemical processes, since atoms cannot be decomposed any further. The answer of science is: No! The atoms may enter into combinations which absorb enormous quantities of heat. A few years ago Curie discovered that radium continually evolves heat. It has been found since then, that radium compounds generate helium under liberation of about 2000 million calories per gramme of radium. At higher temperatures this process must take place in the inverse direction under consumption of this simply inconceivable amount of energy. We have been studying these phenomena only for so short a time that we cannot speak with anything like full clearness. But there is nothing against the assumption that, at still higher temperatures, chemical processes will take place which require much greater quantities of heat per gramme of matter entering into combination. The epoch-making chemical discoveries of Rutherford and Ramsay leave our fancy almost free play in this question.

At ordinary temperature the radioactive bodies are decomposed; at higher temperatures they are re-formed from their decomposition products, when the latter are present in the requisite quantities. The higher the temperature, the smaller the quantity of these decomposition products, and at sufficiently high temperatures the latter will scarcely be existent any more. According to the researches of Strutt this condition would occur at relatively low temperatures, such as we assume for a depth of about 70 km. under the surface of the Earth. Strutt attempts to explain the fact that the temperature increases as we penetrate into the depths of the Earth, by the assumption of a gradual decomposition of the radium contained in the Earth crust. In the common rocks which make up this crust he found on an average eight grammes of radium per million cubic metres. If the whole Earth should, on an average, contain as much radium, that radium would by its decomposition liberate about 30 times as much heat as the Earth is actually losing by radiation into space. We cannot very well assume, that the radium is confined to that portion of the Earth which is formed by the crust of 70 km. thickness and which constitutes the one-thirtieth of the whole globe. We therefore have to consider the probability that at still greater depths radium will be formed from its decomposition products,

if present there in sufficient quantities. The temperature would have to be something like 2000°. At a certain temperature uranium must also be formed from its decomposition products, one of which is radium. For these reasons we need not be surprised that radium has not been discovered in the solar spectrum, as we assign a temperature of more than 6000° to the Sun.

No quantity of uranium worth mentioning is produced from its decomposition products at ordinary temperature. According to Rutherford, uranium is being decomposed at a rate such that in 7000 million years only half of it would remain. Rutherford further concludes that a cubic centimetre of helium is formed from one gramme of uranium at a pressure of 760 mm. and 0° within 16 million years. Now a certain mineral, fergusonite, contains 26 cubic centim. of helium per gramme of uranium. We may hence assume that the uranium of this mineral will have been decomposed in the space of 26 times sixteen million years, that is to say, in 416 million years. So long a space of time must have elapsed since this mineral could have been formed from the glowing masses thrown up from the interior of the Earth (compare "Worlds in the Making," page 43).

The masses of radioactive minerals, which are ejected by a sudden eruption from a sun and then cool down in space, will of course emit radioactive rays in abundance. There may be also

present radioactive compounds which are rapidly decomposed, and which we do not know on the Earth, because they would long since have been transformed. But it is not at all improbable that the strong radiations, which are observed from the nebulous portions surrounding new stars, may partly be radioactive in nature; they need not entirely be due to electrically charged dust particles repelled by the new star.

The nebula formed at the time of the flashing-up of a new star loses its helium by absorption of radiation from space. The helium is condensed upon cosmic dust and thus wanders back into denser materials. By the concentration of the matter the temperature of these parts is increased, and strongly radioactive bodies are once more formed. It is similar with other explosive, though not radioactive, compounds. The nebulæ thus collect, not only the particles of dust which drift into them and other matter which had been expelled by the Sun and transported by the radiation pressure, but also the energy which had been radiated into space. These stores of dust and of energy are gradually accumulated in those portions of the nebula which are nearest its nucleus, and especially in the interior their temperature will be high. There they are re-transformed into radioactive and explosive compounds endowed with enormous energy; and when the Sun into which the nebula had turned once more begins to lose

more energy by radiation than it receives from outside, these bodies will gradually be re-decomposed during the subsequent slow fall of temperature. The vast stores of energy, however, will retard this cooling and maintain radiation at an almost constant rate during the course of thousands of millions and even millions of millions of years.

It will be granted that in this way nothing need be lost of energy, nor of matter, in the Universe. The energy which the suns lose is re-found in the nebulæ, which in their turn play the part of the suns. Thus matter passes through a continuous cycle of stages of energy absorption and energy emission. Nothing more is required for this purpose but that the masses of gas situated in the colder parts of the nebulæ and the particles of dust which have immigrated should absorb the immense amounts of energy which were lost from the suns by radiation. The little that a few years' study of radioactive phenomena has taught us indicates that small quantities of matter are capable of concentrating in themselves stupendous stores of energy.

We must now regard the interior of the Sun as a heat magazine of this kind. During its cooling the chemical reactions proceed in the inverse sense as during the contraction, and great quantities of heat are liberated which will amount to several billion calories per gramme. Since now every

gramme of the Sun's mass loses on an average only 2 calories per year by radiation, it is evident that this process may continue for billions of years. It may also have continued for long periods in the same manner, without any noteworthy diminution, during the thousand million years which geologists demand for the existence of life on the Earth. It is certain that the oldest known organisms which have left traces in the fossils of the Cambrian Age must have lived under temperature conditions which did not much differ from those of the present day. These organisms had reached so high a degree of development that we may surmise that the period which elapsed between the first appearance of one-cell organisms and the time of the Cambrian Age must be as long at least as that which has passed since the Cambrian Age. The organisms embedded in still more ancient geological strata were either too perishable to be preserved in the fossilised state, or they have been destroyed in the course of time under the influence of the enormous pressures and high temperatures, or of both combined, to which those strata must have been exposed for millions of years.

Having thus convinced ourselves of the physical possibility and the reasonability of the cyclic character in the changes of the Universe, by contrast to the "thermal extinction" of Clausius or the "degradation" of Kelvin, we will now turn to consider some special points which have come up

during this discussion. We will proceed graphically, and since we cannot apply our consideration to the whole infinite Universe, we will confine ourselves to that portion of the Universe which permits of observation. This portion is so big, however, that in its complex composition of nebulæ, cosmic dust, dark masses and suns, it will probably deviate little from that of other portions of similar size. We shall probably be able to apply the conclusions which we draw with regard to the part under examination to any other part of the Universe, and hence to the whole of infinite space. We shall first try to find an expression for the total deviation of temperature from the mean temperature of that space. For instance, let the average temperature of the Sun be ten million degrees and the average temperature of matter in that portion of the Universe under examination one million degrees. Then the deviation of the solar temperature from the mean temperature will amount to nine million degrees. If we multiply this figure by the mass of the Sun, we obtain the share of the Sun in the total deviation. To be exact we should, however, divide the Sun into two parts, an inner one whose temperature will be more than one million degrees, and an outer one with a temperature below that average, and we should calculate for each of these parts the partial product of mass and deviation from the mean temperature, and then form the

algebraic sum of the two terms without regard to their signs, plus or minus.

We apply the same procedure to a nebula, for instance, to the great nebula of the belt of Orion. In this case the product will no doubt have a negative sign, since the nebulæ are cold. After having performed this operation for all stars, nebulæ, planets, and for drifting masses of dust and of meteorites, we sum up the products thus obtained. The sum, which will be of huge magnitude, we call A. In our diagram the future is plotted as positive, the past as negative, and the present corresponds to the zero line (Fig. 28).

What will happen? Let us first follow the reasoning of Clausius. According to the law of entropy temperature tends towards equalisation, that is to say, the total deviation, which is A at present, will be less to-morrow, and within a certain time, say, in 10 million years, will have diminished to B. The process goes on; but since the temperature differences will be smaller than before, the equalisation will proceed at a slower rate. The curve which marks the change of A in the course of time will therefore be less steep beyond B than it was in starting from A. Though there will be a further fall in any case, the total deviation from the average temperature will become less, finally, as the mathematician says, to approach the zero limit asymptotically. After a sufficiently long time the deviation will have any small value

imaginable or, in other words, after an infinitely long space of time its value will become zero.

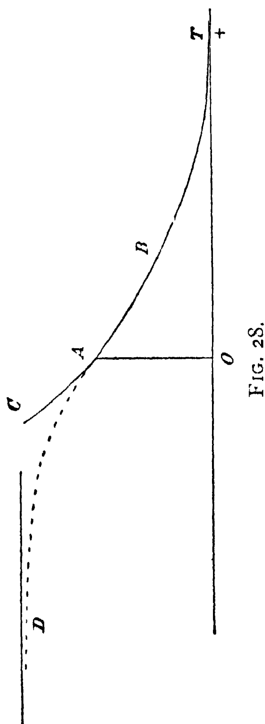


Fig. 28.

Now let us go further back in time. For reasons indicated the A curve must then have been steeper than at present. At a certain time, say 10 million

years ago, the total deviation was C, and if we carry our consideration back far enough, it may have had any value whatever greater than A. The mathematician would say that infinite ages ago the deviation must have been infinitely large. That, however, could only be the case if certain portions of the Universe, which are not visible to us, had an infinitely high temperature, and that again would involve that the average temperature and therefore the energy must have been infinitely large an infinitely long time ago. That is inconceivable in itself; and since we know in addition that the energy within the respective portions of the Universe must have had a finite, although certainly very large value, and that the total quantity of energy is invariable, it cannot a long time ago have exceeded any imaginable high value.

That hypothesis is hence untenable. Some physicists have attempted to find a way out of this difficulty in the following way. Though the inequality of temperature might conceivably, in past ages, have been greater than now, the equalisation may have proceeded at a slower rate, for instance, along the curve D A in Fig. 28. The temperature deviation would then have diminished at infinite slowness at first, afterwards, starting from a finite value at D, more rapidly, to proceed at a great velocity just at present, and to diminish again down to zero finally.

In other words, the world would have been lying dead for countless ages, just to develop with an amazing rapidity in the ages, with which geology and palæontology acquaint us, gradually to fall back again into the eternal inactivity of death. In order to show that this hypothesis is unthinkable and contrary to all scientific reasoning, Christiansen has suggested the following consideration. A heap of gunpowder may lie for a long time without undergoing any visible change. Somebody sets fire to it, or lightning ignites it ; the powder flashes up, and the so far extraordinarily slow changes suddenly become so accelerated owing to the high temperature that an enormously rapid transformation is accomplished within a fraction of a second. There follows a slower chemical reaction, which will last for a few minutes and during which the products of combustion will react with the moisture of the atmosphere. That seems to be the end. The fraction of a second, utterly insignificant by comparison with eternity, during which the powder was flashing up, would correspond to that period of the evolution of the Universe about which we know something. But hardly any scientist will accept this comparison after a closer examination. There is, for instance, the difficulty that powder, as chemists teach us, is subject to slow changes even at low temperatures, changes which would be reduced to zero value only at absolute

zero temperature. Nor can we imagine that the world might, in previous ages, have developed at an extraordinarily slow rate, because the average temperature had been very low in those days. That assumption would be quite unjustified. On the contrary, we should in that case, as Christiansen recognises, have to assume that forces so far unknown in Nature had come into play in the evolution of the Universe. " That possibility lies completely without the range of our experience." It is impossible to argue on those lines.

We might deal with entropy in a similar way. The deduction would be more strictly scientific, but also less plausible. So far as the evolution of the Universe is concerned, the result would be the same. The deviation from the mean temperature in that portion of the Universe which we consider will have kept fairly constant in the course of time. With our Sun the deviation decreases gradually ; but that diminution is compensated for by the rise in temperature which accompanies the transformation of a nebula into a star.

That conclusion also holds for entropy. Its value must on the whole have remained almost unchanged. On the one hand it is continuously decreased by the radiation of the Sun towards the cold nebulæ. On the other hand it is increased by the departure of the most rapid molecules of the light gases of the nebulæ and their accumulation upon the denser aggregates of matter.

If we again confine ourselves to a small portion, like our solar system, of the whole Universe, we have to consider that its average temperature is by no means constant. At the present time it is diminishing. This diminution must finally become very slow, when the Sun will be extinct; and some day when the extinct Sun will have been changed into a nebula by a collision, the diminution will turn into a temperature increase which will continue for a long time after the re-initiation of the solar state.

Thus Spencer's suggestion of a continuous periodical change in evolution holds for every separate solar system. But we cannot speak, with him, of a rhythmic change. For the respective periods in the Universe of suns will no more be regular than those of the oscillating movements of molecules. Length and events of the period will be dependent upon the collision with another body, sun or molecule, which is subject to accidental circumstances, and those features will affect the later development.

It is peculiar to see how the time idea has gradually altered. The above-mentioned estimate of Cicero, according to which the Chaldæans were said to have conducted astronomical observations for 340,000 years, shows that in antiquity man was not startled by the idea of a very long pre-existence of the Earth. Indian philosophers believed in countless ages. During the Middle

Ages that belief was entirely lost. Rhabanus Maurus states in his great work " De Universo " (at the beginning of the ninth century) that the fossils which were found high up in the mountains came from three great universal floods ; the first at the time of Noah, the second at the time of the patriarch Jacob and of his contemporary King Og, the third at the time of Moses and his contemporary Amphitryon (a mythical grandson of Perseus). The age of the world was then estimated very low indeed. Snyder relates in " The World Machine," that Bishop Usher, the contemporary of Shakespeare and Bacon, had calculated from the Jewish chronicles, that the world had been created 4004 years before the beginning of our era, in the first week of January, and that date is to be found printed in English bibles up to the present day. Buffon calculated the time required for the cooling of the Earth from the state of incandescence, which it was supposed to have possessed at the moment of its separation from the Sun, down to its actual temperature. His estimate was 75,000 years. Our studies of the excavations made in Babylon and Egypt prove that a rather high state of civilisation prevailed over there 7,000 or 10,000 years before our era. The coloured outline pictures which are found in the grottoes of the so-called Magdalenian period in Southern France and in Spain, and which are very true to Nature, are credited with an age of about

50,000 years, and the most ancient finds unquestionably of human origin may have an age of 100,000 years. Man was certainly in existence before and during the glacial periods which visited the northern portions of our continent several times at the conclusion of the Tertiary Age. And lastly geologists believe that life in highly developed state must have been in existence for a thousand million years, and that the first signs of life made their appearance possibly twice as long a time ago. We thus approach the high figures which Indian philosophers suggested for the development of life on our Earth.

We have come to our last question, how the conception of eternity can be applied to the existence of life. On the whole naturalists incline to the belief that live matter owes its origin to physical and chemical forces such as are now at work on the Earth. In this respect the opinion of the majority does not essentially differ from that of primitive races (compare Chapter II). Others teach that life came to the Earth from space. We meet with this belief in the Norse legends, in the narrative of the immigration of several gods and of a human couple from the grove near Mimr's well (which corresponds to universal space). That opinion has found many eminent adherents, among them the distinguished botanist Ferdinand Cohn and Lord Kelvin, perhaps the greatest physicist of our age. The great

difficulties which so far attached to this view, I have tried to remove by introducing the radiation pressure as impelling power for the transport of germs through infinite space. That this thesis has found support, in spite of the great difficulties with which it had itself to struggle, is accounted for by the fact that people finally grew tired of refuting over and over again the statement, which was proclaimed every year with the same exultation, that somebody had after all succeeded in calling forth life from dead matter without the intervention of germs. The question is in about the same stage as the problem of the "perpetuum mobile" was half a century ago. The problem of spontaneous generation in its actual form, will, it is to be expected, be deleted from the scientific programme, just as the "perpetuum mobile" has been discarded. There is hardly anything left to us then, but to assume that life came to the Earth somewhere from space, i.e. from formerly populated worlds, and that life itself is eternal like matter and like energy. Yet for the present there remains one very essential difference which renders it difficult to establish the eternity of life. We cannot measure life in its various aspects quantitatively as we measure matter and energy. It is evident that life may suddenly be annihilated without necessarily giving rise to other life. Buffon had his own peculiar views on the indestructibility of the "life-atoms."

To detect means of measuring the quantity of life would be a revolutionary discovery which may never be made. We can yet comprehend the eternity of life. There will always be in the eternal cycle of Nature cosmic bodies favourable to life which will certainly harbour living beings. We may hope that the thesis of panspermia will conquer. If it prove victorious, it will have a very important bearing upon biological science, just as the doctrine of the indestructibility of matter has become most fruitful for the further development of exact science in recent years.

One important conclusion we may already anticipate. It is that all living beings of the Universe must be related to one another, and that when life begins on any body of the cosmos, it must commence with the lowest known forms to rise in slow evolution to more highly organised types. The albumins must under all conditions form the material basis of life, and notions such as that there may be living beings upon the Sun, must for ever be relegated to the domain of phantasms.

Most of the philosophers have been adherents of the eternity of life and opponents of the doctrine of spontaneous generation. It will be sufficient to recall in this connection the above-mentioned words (compare page 48) of the philosopher Herbert Spencer, to whom we are perhaps more indebted than any one else for

elaborating a consistent philosophy of evolution. Another remark of his runs as follows:

"The hypothesis of special creations (living beings rising from lifeless matter or from nothing) cannot be formed into coherent thought. It is one of those illegitimate symbolic conceptions, so continually mistaken for legitimate symbolic conceptions because they remain untested. We cannot elaborate the idea into something like definite shape. . . . Those who entertain the proposition that each kind of organism results from a divine interposition do so because they refrain from translating words into thought. The hypothesis of special creations turns out to be worthless."

Cuvier carried the creation theory to an extreme. He believed with d'Orbigny that the great convolutions of Nature, which he ascribed to volcanic eruptions, had killed and would kill everything alive, and that new specimens had to be created in the place of those destroyed. This view is now altogether abandoned. Yet it contained, as Frech has recently shown, a sound nucleus. We need only replace the volcanic eruptions by the great climatic changes which are generally known as the glacial periods. During those periods many species of plants and animals were destroyed, and they were soon afterwards, when the cold had gone, replaced by new species which had survived or had meanwhile been evolved.

The American physiologist Jacques Loeb has

drawn attention to the influence of the alkalinity of the sea-water upon the production of cross-breeds. In ordinary sea-water eggs of a Californian sea-urchin, *strongylocentrotus purpuratus*, are not fertilised by the semen of the star-fish, *asterias ochracea.* If, however, a four per cent solution of caustic soda is added to the sea-water, in the proportion of three or four cubic centimetres per litre, the fertilisation is entirely successful. Since now the alkalinity of the sea-water increases during periods of low percentages of carbonic acid in the air, it is not unlikely that during the glacial periods new species may have been produced while life in general was much enfeebled. When the warmth returned and the soil was free again, a competition arose, so to say, with the new species, and the better fitted species will have found favourable conditions for their development.

Before we leave the discussion of panspermia, we may perhaps touch upon certain correlated features which have quite recently been elucidated by experimental researches. The possibility for living organisms to wander, by the aid of the radiation pressure, from one planet to another belonging to a distant solar system is conditioned by the low temperature of space. Low temperature can so strongly check and diminish the vital activity that life may be sustained for millions of years. Madsen and Nyman, as well as Paul

and Prall, have conducted some very remarkable experiments on the influence of temperature on the preservation of life. The former examined the endurance of anthrax spores at different temperatures. At low temperatures, in an ice cellar, for instance, they can be preserved for months without losing much of their germinal powers, whilst a few hours at 100 degrees will kill them. It is interesting that temperature here exercises the same general influence as upon special vital processes. Reactions generally take place two and a half times as rapidly as before when the temperature is raised by 10°. I have made this ratio the basis of my calculations concerning the preservation of the germinal power at low temperatures.

While these experiments were conducted at temperatures above the freezing point of water, those of Paul and Prall were performed at the boiling point of liquid air, at −195°. They took vegetative organisms (not spores) of staphylococci (a kind of bacteria) in the dried state. At ordinary (room) temperature half of the bacteria perished within three days; but their vitality did not decrease noticeably, when they were kept for four months at the temperature of liquid air. That is a very beautiful proof of the remarkable preserving influence of intense cold upon the germinal power. We assume that the most intense cold prevails in the empty space intervening between solar systems.

We might revert to the comparison between the problems of the "perpetuum mobile" and of spontaneous regeneration in one respect. Experience forces the conviction upon us that eternal movement under performance of work is impossible, considering the actual conditions on the Earth and in the solar system in general. But we must also admit that the one exceptional case which Maxwell suggested might play an important part upon nebulæ, those cosmic bodies which may be regarded as the counterparts of the suns. Thus although, as far as we can judge, spontaneous generation is no longer possible on Earth and probably was no longer possible under the similar conditions of previous ages, this phenomenon might conceivably take place elsewhere in the Universe, under materially different physical and chemical conditions. From the spot or from the spots, where spontaneous generation was possible, life might have spread over to the rest of the habitable bodies of the Universe. When we take the idea of spontaneous generation in this sense, it becomes much more probable than when we assume, that life would have arisen without germs on every one of the infinite number of cosmic bodies, on which we fancy it to thrive.

It is clear on the other hand that the world, taken as a whole, has been in existence for infinite ages and under conditions similar to those which prevail at present. Hence life must always have

been in existence, however far back we may carry our thoughts.

In this last chapter we have striven to prove that, before the fundamental laws of Nature (those of the indestructibility of energy and of matter) were definitely formulated, these laws had more or less consciously been in the minds of the various philosophers. It might possibly be said, that it would have been much more reasonable to accept the views of those philosophers without further ado and without waiting for their verification by scientists. That might pass if different, directly contradictory opinions had not so often been proclaimed at the same time. Under those circumstances verification by experiment was indispensable.

There is further a great difference between those philosophical speculations and the later deduced laws of Nature. When, for instance, Empedokles or Demokritos teach that matter is imperishable, whilst their time generally held the opposite view, that is something entirely different from Lavoisier's demonstration, that a metal becomes heavier by absorbing oxygen from the air, and that the increase is exactly equal to the weight of the oxygen bound by the metal. This experiment of Lavoisier is only one of the many demonstrations given by chemists every day which prove that the conclusions drawn from the theory of the indestructibility of matter never mislead us.

It is similar with the philosophical considerations of Descartes, Leibniz, and Kant concerning the gradual self-combustion of the Sun. There was a dark suggestion of the idea that energy cannot rise from nothing. But it was only after Mayer's and Joule's experimental demonstrations that, whenever a certain quantity of energy disappears (for instance, in the shape of work) a corresponding quantity of energy is always generated (for instance, in the shape of heat), that we could assert with perfect certainty, that the energy store of the Sun must, owing to radiation, continuously decrease and finally be used up altogether, unless it can be replenished in some way or other. Before this fact was fully recognised, the most ingenious men like Laplace and Herschel had found no contradiction in the assumption, that the solar radiation might continue in all eternity without decrement. This is indeed still the common notion, as it seems to agree with our daily experience. Kant's idea of the ever-recurring renewal of the Universe which—so generally held — deserves all praise, brings us yet into contradiction with the principle of the indestructibility of energy. The same criticism must be applied to the thesis of Du Prel.

With Kant the idea of repetition in the history of the Universe is based upon an ethical principle. He finds " contentment " in the thought that the world will continue to bear organic life. It would

interfere with his belief in divine perfection, if the suns were to remain for ever extinct. Spencer starts from a more objective point of view, when he assumes that there is a certain regularity in the development of the Universe. He stands on the modern platform that the world has been in existence through infinite time—while Kant thought that it had been created—and that it cannot have an end. His alternating periods of concentration and of diffusion of matter remind us of the Indian periods of rest and of activity. The solar system, Spencer considers, is a system in moving equilibrium which will finally be so distributed that it again becomes the attenuated matter from which it arose. How such a dissipation was to be brought about, since nothing but the one impelling force, Newton's gravitation, was known, is incomprehensible. Spencer certainly speaks of collisions between celestial bodies, but he does not ascribe any importance to them and does not make them factors in his diffusion phenomena. If there were no repelling forces, all things in the Universe would concentrate.

The introduction of the conception of the radiation pressure and the proof that, under certain conditions, entropy may decrease, have at last enabled us to work out the idea of an eternal cyclic development of the Universe, on which Indian philosophers were brooding in the grey past.

Ideas fare like organisms. Seeds are sown in multitude, but only a few will sprout ; and of the living organisms which rise from them, most succumb in the struggle for existence. There is an analogous selection of the fittest in the thesis of natural philosophy. We often have to hear that it is useless to trouble about theories, since they rise only to be overthrown again. Whoever speaks thus, lacks insight into evolution. The theories which we accept at present have their roots in notions which go back to the earliest ages. From dim dark notions they have grown into clearly defined doctrines. The vortex theory of Descartes had to be abandoned, when Newton demonstrated, that there could not be any great quantities of matter in space. But other speculations of Descartes, his suggestion of the formation of the solar system from a nebula in original rotation, for instance, have survived. We also recognise his immigration of planets from space into the solar system in the view of Laplace, that migrating comets had their share in the formation and movements of the planets, as well as in the suggestion, that the attraction centres of the planetary nuclei in the solar system, had come from outside.

Nothing can be more mistaken than to state that time spent in theorising on cosmogonical problems is wasted, and that we shall never advance beyond the knowledge of the ancient

philosophers, simply because we admit that their speculations contained elements of truth. Modern cosmogony has indeed advanced at a far more rapid rate than ever before, and the obvious reason is that natural science is flourishing as it has never done before. We may rejoice to observe, how humanity has been progressing at an accelerated pace in the course of centuries. This book contains many an exemplification. It will not be denied that, on the whole, the conceptions of an all-embracing nature and of freedom and manhood have advanced and receded simultaneously. Culture and civilisation expand, when the human race advances. And we find in particular that the scientist has, in all ages, spoken for humanity.

He who opens his eyes to the possibilities of evolution in their endless variety will abhor fraud and violence and disdain prosperity at the expense of his fellow creatures.

THE END

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